WATER RESOURCES IN THE ONAKAWANA AREA AND THE ANTICIPATED IMPACT OF THE PROPOSED LIGNITE AND POWER DEVELOPMENT

Ministry of the Environment

Ontario

The Honourable
George A. Kerr, Q.C.,
Minister

K.H. Sharpe,
Deputy Minister

TASK FORCE ONAKAWANA
WORKING PAPER #2

WATER RESOURCES
IN THE
ONAKAWANA AREA
AND THE
ANTICIPATED IMPACT OF THE
PROPOSED
LIGNITE AND POWER DEVELOPMENT

SURFACE WATER RESOURCES	by	W. LAMMERS
GROUND WATER RESOURCES	by	K. T. WANG
WATER QUALITY	by	M. J. GERMAN A. C. ROY

WATER RESOURCES DIVISION

MINISTRY OF THE ENVIRONMENT

October 1972

LIST OF TABLES

TABLE OF CONTENTS

LIST OF FIGURES

Page No.

SURFACE WATER RESOURCES

INTRODUCTION

This section deals with the drainage pattern in the Onakawana area, the quantitative aspects of streamflow of the Abitibi River at Onakawana (4ME-3), Otter Rapids (4ME-4), Abitibi Canyon (4ME-2), Island Falls (4ME-1) and Iroquois Falls (4MC-1), the Moose River at Moose River Crossing (4LG-2), the Mattagami River at Smoky Falls (4LG-1) and at Little Long Rapids (4LG-3). Detailed streamflow analyses were carried out on data collected at four stations in the lower Moose River Basin. Their locations are shown on Figure 1.

The adverse effect of present streamflow regulation at the upstream power dams on the maintenance of adequate and dependable flow of the Abitibi River in the Onakawana area is also discussed.

DRAINAGE PATTERNS

The Onakawana lignite deposits are located at the northeast part of the Moose River Basin about 60 miles south of Moosonee. The general land surface of the area is flat with an elevation of about 175 feet above sea level and a gradient of about 4 feet per mile toward James Bay.

The flatness of the area causes an imperfect drainage. Wet muskeg and peat of 2 to 8 feet in thickness covers all of the area except for a small part near the Abitibi River where drainage is sufficient for normal tree growth.

The area is drained by three rivers of which the Abitibi River is the largest.

The Abitibi River drains 10,600 square miles, the Onakawana, about 316 square miles, and Medicine Creek about four square miles at Onakawana.

At Onakawana the Abitibi River valley is about 1,200 feet wide and its river banks are 40 to 50 feet high. The Onakawana River valley is about 78 feet wide, its riverbanks are 20 to 30 feet high and quite steep near its confluence with the Abitibi River. The Medicine Creek valley is about 21 feet wide at its mouth and its banks are quite low.

Streamflow records are available for the Abitibi River at Onakawana. One flow measurement each was taken by Branch staff on the Onakawana River and Medicine Creek. The Onakawana River was gauged on July 24, 1972, and a flow of 268 cfs was obtained. Medicine Creek was gauged on July 25, 1972, and a flow of 13.6 cfs was obtained. Their flows reflect the effects of precipitation that had fallen the preceding week.

The Mattagami River flows about five miles to the west of the Abitibi River at Onakawana. It has a drainage area in excess of 14,000 square miles above the Onakawana area.

STREAMFLOW ANALYSES

Streamflow analyses consisted of the preparation of duration hydrographs, showing traces of the maximum, median and minimum seven-day mean discharges throughout the calendar year as well as flow duration and

low-flow frequency curves for the selected locations. These curves emphasize the variability in flow distribution within the selected period of record.

Flow Duration Analysis

A flow duration curve is a cumulative frequency curve that shows the percentage of time specified streamflows are equalled or exceeded during a given period.

Duration curve data of seven-day mean discharges were determined for each of 52 specified seven-day periods(1) in a year utilizing daily streamflows for the period of record. Traces of the maximum, median and minimum seven-day mean discharges were prepared to show the magnitude and range of flows over the selected period of record for these 52 seven-day periods.

Duration curves of daily flows were prepared for the Mattagami River at Little Long Rapids and Moose River at Moose River and duration curves of both daily and seven-day moving average flows were prepared for the Abitibi River at Onakawana. Such curves show the flow characteristics of a stream throughout its range of discharge and period of record without regard to the sequence of streamflow events.

Low Flow Analyses

Low flow frequency analyses were done and frequency curves were prepared for the summer, fall, winter and annual periods. A distinction was

(1) The seven-day periods have fixed calendar dates for meaningful assessment, necessitating the last period of each year and the period February 26 to March 4 during a leap year having eight days.

made between the summer-fall and winter periods as the flows during these periods are generated under widely varying hydrologic conditions. Also greater demands are generally placed on the water resources of a river during the summer-fall or open-water period than during the winter when severe freezing conditions prevail. Furthermore, when a river is being considered or used as a source of cooling water, such as for a thermal electric power station, the background temperature of the river water during the open-water, low-flow period would be a very important constraint on the permissible heat input into the river from such a thermal station. In most situations the highest background water temperatures would coincide with the lowest river flows during the summer-fall period.

For this study the summer-fall period was arbitrarily taken as May 1 to October 31 and the winter period as November 1 to April 30. The frequency curves based on the open-water, low-flow period yield more reliable values than those based on the winter period due to differences in the quality of flow records. Often winter flows are not accurately defined and records are not always available for individual days, but rather for a variable number of days.

As the natural streamflows in both the Abitibi and Mattagami rivers are greatly modified due to flow regulation by Ontario Hydro and private power and paper companies upstream of the Onakawana study area, low-flow frequency curves were prepared to portray the annual low flows resulting from the upstream regulation.

STREAMFLOW SUMMARY

Streamflow parameters are summarized for the various analyses of streamflow at the gauging station locations on the rivers of interest for the Onakawana Power Development and are presented in Tables 1 to 4. Mean daily discharges are summarized in Table 1. Estimates of the lowest mean discharge that would occur at 2, 5, and 10-year average recurrence intervals for 1, 7, and 30 days during the annual, summer-fall and winter periods are presented in Table 2. The flow ranges of the minimum, median and maximum values of the 52 consecutive seven-day mean discharges are presented in Table 3.

Mean daily and seven-day moving average discharges of the Abitibi River at Onakawana for selected percentages of time are tabulated in Table 4 for comparison purposes.

To show the chronological sequence of streamflow in the Abitibi, Mattagami and Moose rivers sample hydrographs were prepared and are shown in Figures 18, 19, and 20.

ADVERSE EFFECTS OF EXISTING RIVER REGULATION

Control dams and hydro-electric power stations have been built on both the Abitibi and Mattagami rivers upstream from the Onakawana area. Past flow regulation has adversely affected the dependable low flows downstream of these control works for periods of up to two consecutive days. The effects on the Abitibi River flows are very pronounced due to the fact that this river is often completely turned off upstream from Onakawana. At Iroquois Falls

the flow is released very uniformly over a six-day period followed by a one-day period when the flow is greatly reduced and often completely turned off. Figure 18 shows a hydrograph of mean daily flows of the Abitibi River at Iroquois Falls for the recent period, July 1 to December 31, 1970. The effect of this type of regulation is clearly shown. As a matter of fact, the river was completely turned off for seven non-consecutive days and at other "off" days the river flow was reduced to about a third of that normally released on the previous six days. It is important to note that the Abitibi River drainage at Iroquois Falls is about half that of the river at Onakawana.

The effects of such regulation become more and more muted at downstream gauging locations due to additional inflow into the river from the drainage area below Iroquois Falls. Figures 18 and 19 show this clearly.

The adverse effects of regulation on the Mattagami River are not as pronounced on the hydrograph of daily flows plotted on Figure 20. The duration curve of daily flows of the river at Little Long Rapids (Figure 4) shows the effects of flow manipulation at upstream control works more clearly. As a matter of fact, flows at this site were observed that were lower than on the Abitibi River at Onakawana.

The frequency curves of the lowest one-day average flows of the Abitibi River at Onakawana (Figures 6, 7 and 8) and the Mattagami River at Little Long Rapids (Figures 9, 10 and 11) suggest severe flow reduction due to upstream regulation.

In order to arrive at a better appreciation of the dependable water resource potential of the Abitibi River at Onakawana, a duration curve of seven-day moving average flows was prepared and is shown in Figure 2. It was found that the minimum seven-day average flow was 4,500 cfs. This value shows that with regulation at Onakawana a much higher flow of water can be obtained than the minimum one-day average flow of 700 cfs. The comparative flow values of seven-day moving average flows versus one-day average flows for selected duration levels are listed in Table 4.

The amount of storage required at Onakawana will depend on the operating procedures at the upstream control works and on the mode of operation at any control works at Onakawana.

IMPACT OF WATER USE ON STREAMFLOW

1. Withdrawal of Water

The streamflow evaluation of the Abitibi and Mattagami rivers near the Onakawana area confirms that, because of inadequate flows at certain times of the year, these rivers can be used as a source of withdrawal of water at about 800 cfs on a continuous basis. Both rivers have experienced mean daily flows less than the estimated flow requirements for cooling water purposes for two days in a row. On an annual basis there is a 10 per cent probability that the minimum one-day average flow of the Abitibi River at Onakawana and the Mattagami River at Little Long Rapids will be less than 700 and 300 cfs, respectively. There is a 20 per cent probability (one in five year return period) that the one-day average flow of these rivers will be less than 1,000 and 700 cfs, respectively.

The water resource picture in terms of the minimum seven-day average flow is much better. There is a 10 per cent probability that the minimum seven-day average flow of the Abitibi and Mattagami rivers at the previously defined location will be less than 4,200 and 3,700 cfs, respectively. Similar values at the 20 per cent probability level are 5,000 and 3,900 cfs, respectively.

Different operating procedures at upstream river flow control works or the construction of a buffer reservoir downstream of these works or a combination of both these means would improve short-term minimum flow conditions and make the rivers more attractive as a source of water for use on a continuous basis.

2. Return of Cooling Water

Using the river as a source of cooling water for a thermal-electric generating station of 1,000 megawatts would require a dependable flow in excess of 800 cfs to satisfy the cooling water requirements for the power plant; a much larger flow would be required if this cooling water were to be returned to the stream if suitable maximum river temperatures, commensurate with the present aquatic ecosystem, are to be maintained.

Figure 21 can be used to determine the flow of water required to lower the temperature of the returning cooling water of 800 cfs and known temperature and to determine the net increase in river water temperature above ambient after complete mixing between these waters. The curves shown are based on equation $\Delta T_R = Q_c \cdot \Delta T_c / Q_R$ and on the following two assumptions:

(1) Ambient river temperature above freezing.

(2) No heat loss from cooling waters to the atmosphere nor to the bottom and banks of the river. For instance, to determine the amount of water required to limit the increase of river water temperature by four Centigrade degrees as the result of a heat input of 800 cfs at 20C° above ambient river temperature one would read from the upper curve of Figure 21 the value of 4,000 cfs at the 4C° level. The curves represent slightly more severe conditions than would actually occur as there would be heat loss to the atmosphere and surroundings.

Aquatic ecologists would have to evaluate what temperature rise would be acceptable under extreme and under average conditions. The curves shown in Figure 21 could be used to determine the flow ranges that would be required to meet the standards set by the ecologists. Engineering studies would then be initiated to study the feasibility of providing the recommended flow ranges and at what cost.

GROUND WATER RESOURCES

INTRODUCTION

The following report on the hydrogeology in the Onakawana area is the result of a one-week field investigation undertaken to obtain an appreciation of the ground water resources by determining the general hydraulic properties of the geologic formations in the area. The test results are general and preliminary. The locations of drill holes and shaft are shown in Figure 22.

Geologic information is included in the reports "The Onakawana Lignite Deposit, Moose River Basin" (Dyer, 1930) and "Lignite and Refractory Clay Deposits of the Onakawana Field" (Dyer and Crozier, 1933). The geologic data for this report were based on the above reports and some unpublished data prepared for the Hydro-Electric Power Commission of Ontario.

GEOLOGY AND GROUND WATER OCCURRENCE

The geological formations involved in the transmission, storage and confinement of ground water in the Onakawana area are the recent muskeg and peat deposits, Pleistocene tills, sands and gravels, and the Cretaceous and Devonian bedrock.

Recent Deposits

Recent deposits of muskeg and peat cover most of the area owing to the flatness of the country and the poor drainage conditions. Thickness of the muskeg ranges from zero near the west bank of the Abitibi River to a maximum

of eight feet in the central area between the streams. The water table is generally near the land surface in the muskeg terrain due to the less permeable marine clay below it.

Pleistocene Formations

The Pleistocene deposits in the Onakawana area include marine clay and glacial series. Marine clay underlying the muskeg is of a grey plastic, sometimes silty, consistency. In place this clay contains lenses of sand and gravel. General thickness ranges from about five to ten feet. This clay is very low in permeability and acts as a confining bed for the underlying aquifers. The glacial series in this area consist of two till sheets separated by interglacial series of sands and gravels and stratified clays.

The upper till sheet consists of sandy clay and boulders and is more permeable to water than the lower clay till sheet. The maximum thickness of the till sheets is about 150 feet.

The sand and gravels of the interglacial beds are the principle aquifers in the area. Thicknesses of this aquifer formation average about 15 to 20 feet; however, a maximum thickness of 34 feet has been recorded at drill hole 28 near the northwest boundary of the lignite field.

The stratified clay of the interglacial age is very low in permeability.

Cretaceous-Mattagami Formation

The Cretaceous-Mattagami formation consists of two seams of lignite with interbeds of clay and sand.

Drill logs indicate that the upper lignite seam was subjected to a greater degree of glacial erosion. Thickness of the upper seam ranges from zero, in the many places where it has been eroded, to a maximum of 43 feet in the area near shaft "W". The lower seam has a fairly uniform thickness. It varies from 14 to 22 feet in the east and middle, and from 25 to 30 feet in the southwestern part of the lignite formation.

The lignite beds are composed of woody lignized trunks and roots of trees to fine, earthy and peaty materials. This diversity of material has resulted in a great variation in the ability of the lignite to transmit and store water. In tests conducted at drill hole W-21 in 1972, the permeability of the upper seam was about 30 times larger than that of the lower seam.

The clay beds of the cretaceous age are very low in permeability.

The logs of only a few drill holes show a sand layer in the cretaceous formation. This thickness ranges from three to ten feet. Such sand lenses may be quite permeable to water but their storage is very limited.

Devonian Formation

Logs of drill hole "A" indicate that Devonian beds at depths of 250 feet to 1,027 feet, consist of four distinct formations. The Long Rapids formation was deposited in the continental environment and consists of interbedded shales and clays which are very low in permeability. The underlying Williams Island formation, the Abitibi formation and the Moose River formation were deposited in the shallow sea environment and consist of porous (and cavernous) limestone with interbedded shale. No information on the hydraulic properties of, nor on the water quality in, the formations is available, but

the porous (and cavernous) limestone may be able to transmit and store large amounts of ground water.

Generalized Flow Systems

Based on measurements of water levels in drill hole W-21, the nearby auger hole W-15, and of the Abitibi River (Table 5), the water level in the muskeg is about nine feet higher than that in the lignite beds and the latter is about 26 feet above water level of the Abitibi River where lignite outcrops. At the campsite near the Abitibi River, the water level in the sandy till is about 13 feet higher than the water level in the interglacial sand and gravel formation. The latter is about nine feet higher than the water level in the Cretaceous sand.

It can be generalized that the waters in the formation overlying the Devonian beds are mainly recharged through infiltration of precipitation and leakage through clay beds. These waters are discharged through evapotranspiration and through seepage from outcrops of the aquifers toward the Abitibi River. This flow system is local in nature.

No information on water in the Devonian formation is available. This water is believed to be part of a regional flow system.

HYDRAULIC PROPERTY AND POTENTIAL YIELD

Five field tests were conducted during the period August 9-15, 1972. Two of these were carried out in the lignite beds. Three others were performed in the muskeg, the interglacial sand and gravel and the Cretaceous sand formation, respectively. The results are listed in Table 6. It should be noted that, in absolute terms, all are low when compared to other areas.

Muskeg

The muskeg in the area may have a wide range of permeability. Its coefficient of storage is high but total water storage is small due to the fact the muskeg is thin.

A field test on muskeg was performed in an augered hole, W-15, near drill hole W-21. The coefficient of transmissibility is about 14.5 Imperial gallons per day per foot (gpd/ft).

Interglacial Sand and Gravel

The sand and gravel between the tills is the principal aquifer in the area. Tests conducted in well W-19 indicate a coefficient of transmissibility of 215 gpd/ft. A six-inch diameter well constructed in this formation may yield 4.5 gpm which may be sufficient for domestic use, but would be too small for community or industrial use.

Lignite Beds

Field tests conducted in the upper and lower lignite beds in drill hole W-21 indicate that the coefficients of transmissibility are 222 gpd/ft. and 4.25 gpd/ft, respectively.

Cretaceous Sand

Well W-20 was drilled in 1968 as a source for water supply of the camp site. The well was cased with a five-inch diameter steel casing and equipped with a six-inch long plastic strainer in the sand formation at a depth of 100 feet below land surface. After flushing, the well was tested by the injection method and a coefficient of transmissibility of about 87.8 gpm/ft. was obtained.

GROUND WATER SEEPAGE INTO MINING PIT

Seepage of ground water into the mining pit will vary with the permeability of the saturated porous media and the head difference between the static water levels of the formations and the water level in the pit. It generally decreases logarithmically with time assuming, of course, no recharge conditions. The non-steady flow conditions of seepage is analyzed using the following equation:

$$Q_b = h_o \sqrt{\frac{ST}{kt}} \qquad \text{(Ferris et al, 1962)}$$

The total estimated seepage from the porous formations per foot length of a pit excavated to the bottom of the lower lignite bed will be at the rate of about 0.043 gpm in one day and 0.016 gpm in seven days after the beginning of the watertable lowering. Detailed information on seepage rates is presented in Table 7.

Actual seepage flow obviously will depend upon the local permeability of the various formations and the depth of the pit and the other factors stated above. The above figures are of a preliminary nature and may not be sufficient for design of a mining pit dewatering system. It would appear, however, that this seepage would not be the major problem in maintaining a suitable water level in the pit but rather the removal of precipitation fallen on the pit area. For a thousand-foot mining face 43 gpm would be anticipated one day after the beginning of water level lowering.

IMPACT ON GROUND WATER RESOURCES

1. Effect of Waste Disposal

Large amounts of liquid and solid wastes will be produced as the result of the mining and burning of the lignite as a fuel at the proposed thermal electric generating station. Disposal and storage of the wastes on the ground surface is not expected to significantly affect the temperature and quality of the ground water near the sites because of the relatively impermeable nature of the surficial deposits.

2. Effect on Ground Water Flow Systems and Productivity of Aquifers

Development of the lignite will disturb the geologic formations of the area. The general effect will be a dewatering of aquifers in the immediate vicinity of the mine. Present knowledge indicates that the ground water flow system in formations overlying the Devonian bedrock is local in nature and the productivity of the sand and gravel aquifer is small (less than 10 gpm). Because of the generally low permeability exhibited by the formations the extent of dewatering should be localized. The effect on the entire flow system is therefore expected to be local and the loss of ground water resources due to lignite development will likely be small.

3. Effect of Ground Water Disposal on Surface Waters

Certain amounts of ground water will have to be pumped out during mining operations. The total dissolved solids content of ground waters in the overburden and the lignite beds is less than 600 ppm. No chemical quality problem can be foreseen by introducing these ground waters to streams.

If powdered lignite were to go into suspension in water associated with the mine pit and this water were to be pumped directly into neighboring streams there is a danger that the stream water would be blackened.

The impact of lignite development on ground water resources is expected to be limited. More detailed field studies on the hydraulic properties of the formations would shed light on the real effects of the dewatering program.

WATER QUALITY

INTRODUCTION

The objective of this section is to describe the ambient quality of surface and ground waters in the lower Moose River Basin, specifically in the Onakawana project area. The quantity of data is limited, consisting of chemical sample analyses and some physical parameters measured at the time the samples were taken. The data are listed in Tables 8, 9 and 10. The locations of water sampling points are shown in Figures 1 and 23. The data indicate that iron, colour, turbidity, hardness and temperature are the most significant aspects of surface water quality.

GENERAL WATER QUALITY

The quality of the surface and ground waters in the area is characterized by a low mineral content of silica, calcium, magnesium, sodium, chloride, nitrate and phosphorous. Surface waters of the lower Moose River Basin show very low heavy metal concentrations of zinc, copper, nickel, lead, cadmium, manganese, cobalt and mercury. Due to the low concentrations of these constituents, no problems are anticipated with regard to any types of water use. Iron, colour, turbidity, hardness and temperature could cause problems with regard to some kinds of water use.

Iron

Iron in the surface waters of the lower Moose River Basin varies from 0.15 to 2.6 ppm. <u>Guidelines and Criteria for Water Quality Management</u> indicate that water for cooling should not exceed 0.5 ppm iron. Waters with

these iron concentrations also exceed the 0.3 ppm acceptable limits for public drinking water supplies.

Colour

Colour measurements were done twice on the Abitibi River at Onakawana and both times they were 150 Hazen colour units. The surface waters of the lower Moose River Basin vary from 40 to 250 Hazen colour units. Thus, most of these waters exceed the 75 Hazen colour units permissible for public drinking water supplies.

Turbidity

The turbidity of the Abitibi River at Onakawana is believed to be in the 40 Jackson turbidity units range. This is approaching the maximum tolerable limits of 50 J.T.U. for cooling waters.

Hardness

The surface waters of the lower Moose River Basin range from 75 to 100 ppm hardness, while ground water in the vicinity of Onakawana range from 115 to 375 ppm hardness. Some problems may exist with respect to cooling water since the desirable limit for industrial cooling is less than 50 ppm hardness.

Temperature

With the limited water temperature data available it appears that the Abitibi River at Onakawana ranges from 32°F to 74°F (Table 10). If the upper limit were to increase significantly it could reach lethal levels for

certain aquatic species and may affect the reproductive capacity of some aquatic species and jeopardize the existing aquatic ecosystem. The highest ambient temperatures generally occur during low flows in streams.

ANTICIPATED IMPACT ON AQUATIC RESOURCE

Introduction

On the basis of the absence of final information concerning the details of the proposed development at Onakawana, equally limited data on surface water quality of the area and visual inspections of the site, the following comments are provided relative to the potential impact on the aquatic resource of the proposed lignite mining operation and thermal generating facility.

Thermal Enrichment

The limited temperature data available indicates a maximum temperature of 74^{o}F (July 16, 1969) in the Abitibi River at Onakawana. Flow data for the river at the same location suggests that flow volume under critical conditions is reduced to approximately 700 cfs. Information provided on the proposed thermal generating facility suggests that the cooling water requirements for the 1,000 megawatt plant would exceed the total river flow under low flow conditions so that no water would be available for dilution of the cooling water. Recognizing that the maximum temperature probably occurs coincidental with low flow conditions and the upper lethal incipient temperature of the common white sucker is 86^{o}F, it is readily evident that the Abitibi River has severe limitations both with respect to providing the volume of water required for cooling purposes and the provision of dilution water to protect the aquatic ecosystem from unacceptable temperatures. It should also be recognized that even under higher flow conditions the existing mode of regulating stream flows of the Abitibi River

which allows for extreme daily fluctuations in the volume of flow would result in unacceptable temperature shock to the native fish species and other life forms owing to fluctuating volumes of dilution water.

Thermal enrichment unquestionably constitutes the most serious problem which has to be resolved relative to water quality considerations. While the possibility of using the Abitibi River for once-through cooling is totally unacceptable there are several potential solutions to the thermal enrichment problem which should be explored. Some of these potential solutions are as follows:

(1) Provision of cooling towers or the use of cooling lagoons to reduce temperature of the cooling water to an acceptable level.

(2) Alteration of existing flow regulations on the Abitibi River to ensure an adequate and continuous source of dilution water.

(3) Construction of a storage reservoir on the Abitibi River below Otter Rapids for the provision of the necessary dilution water.

(4) Regulating power production at the proposed generating plant to coincide with periods of streamflow above a specified volume.

(5) Location of the thermal generating facility on the Moose River in order to make use of the larger volume of dilution water carried in the Moose River.

(6) Making use of the dilution capacity of both the Abitibi River and the Moose River through construction of a channel or pipeline to carry a portion of the cooling to the Moose River.

While all of these procedures appear to offer some potential in terms of providing an engineering solution to the problem, it is understood that the present plan is to construct a dam on the Abitibi River at Onakawana. While this might be feasible, it should be recognized that existing information is inadequate to allow a decision in favour of this alternative. In order to reach a decision in this regard, additional information must be obtained and assessed relative to:

a) the stability of the streambed at Onakawana to support a dam structure,

b) the quantity of water which could be provided from such a structure on a sustained yield basis,

c) the temperature profile of river at Onakawana,

d) temperature requirements of aquatic life within the river, and

e) the migratory movements of fish species in the Abitibi River.

Chlorination of Condenser Water

Chlorine utilized for purposes of controlling fouling within the condensers at the proposed thermal generating facility could create serious conditions within the receiving water if adequate dilution is not provided. In this operation a residual of 100 mg/l is normally provided. A residual of this magnitude would be directly lethal to aquatic organisms. For example, trout species will not survive in waters having chlorine concentrations in excess of 0.03 mg/l while the fat head minnow, a more tolerant

species, requires water with no higher than 0.1 mg/l of chlorine. An engineering solution to the problem of thermal enrichment should also take cognizance of the dilution required to produce a safe chlorine residual.

Ash Disposal

The lignite fired furnaces at the proposed Onakawana plant will be equipped with precipitators for removal of fly ash. Any water utilized to transport the precipitated fly ash will have considerable alteration in quality which might require special consideration for disposal purposes. The quality of the water transporting bottom ash will also be altered. It is impossible to predict the precise nature of this water but it is likely to be high in dissolved solids content.

Flow Regulations

The Abitibi River at Onakawana is severely restricted in terms of productivity and usefulness owing to upstream operations at hydro generating facilities which regulate flows for peak power production. The resulting situation in the Abitibi River is a daily fluctuation in flow which exposes approximately four-fifths of the streambed at Onakawana. This factor alone reduces the biological productivity of the river to one-fifth of its potential. Any decision reached relative to the proposed development at Onakawana should take cognizance of the need to stabilize flow conditions in the river.

Diversion of the Onakawana River

In order to develop the lignite deposit it presumably will be necessary to divert the flow of the Onakawana River presumably to the Abitibi

River at a point upstream of Onakawana.

This diversion will result in considerable disturbance of clay particles along the new channel both during the construction phase and as a result of bank erosion once the diversion has been accomplished. While the water quality of the Onakawana River near its mouth will undoubtedly be of poorer quality than its natural state, this condition is not expected to have any detrimental influence on the Abitibi River owing to its existing high turbidity and suspended solids levels. With normal precautionary measures which will be detailed to the company upon official submission of the diversion proposal to the Ministries of Natural Resources and Environment, the net effect on water quality should be minimal.

The Onakawana River is utilized fairly extensively by canoe parties in order to avoid long portages necessary on the Abitibi River in the Long Rapids area. The utility of the Onakawana River for this purpose will not be altered by the diversion since the new channel would connect with the Abitibi River below the Long Rapids.

It is not known if there is a natural movement of fish species to and from the Onakawana and Abitibi rivers. Should such a migration exist, it is probable that the population or populations involved would be sacrificed since the diversion channel would be of poorer water quality than the natural channel and probably unacceptable as a new migration route. Furthermore, if the development will necessitate the construction of a dam on the Abitibi River at Onakawana, a physical barrier would be imposed between the natural

and diversion channels of the Onakawana River.

Mining the Headwaters of Medicine Creek

It would appear that development of the Onakawana lignite deposit would necessitate drainage and physical destruction of the headwater portion of Medicine Creek. The creek is a dark coloured body of water with little gradient and considerable depth. With proper precautions the necessary alteration of Medicine Creek would probably have only a minor influence on water quality conditions in the creek and the destruction of the headwater area would not constitute a serious loss of aquatic life.

Mine Water Disposal

Mine water from the open-pit operation may be of poor quality and unsuitable for direct disposal to any of the water courses in the area. While the available information suggests that the mine water will be alkaline in nature and no pH problem would be anticipated with its disposal, high dissolved and suspended solids concentrations are possible. The most significant problem will probably be one of poor colour and turbidity characteristics which, from aesthetic and biologic considerations, may mean that the water will be unsuitable for direct disposal. Some form of treatment will probably be required.

TABLES, FIGURES AND

REFERENCES

Table 1. Summary of Streamflow Parameters at Selected Stations, Lower Moose River Basin.

Name	Station No.	Drainage Area (sq.mi.)	Selected Period of Record	Streamflow Parameters (in cubic feet per second): Mean Daily Discharges Equalled or Exceeded at Indicated Percentages of Time during Period of Record: 50	80	90	95	99	99.9	99.99	Graphical Presentation in Figures
Abitibi River at Onakawana	4ME-3	10,600	1960-70	11,000	8,200	7,000	6,100	4,200	1,500	700	2
Mattagami River at Smoky Falls	4LG-1	13,400	1927-62	13,400	7,600	4,000	3,300	2,100	980	600	3
Mattagami River at Little Long Rapids	4LG-3	13,400	1964-70	13,400	9,000	5,500	4,700	3,600	1,200	340	4
Moose River at Moose River	4LG-2	23,600	1960-70	14,500	8,300	7,000	6,000	4,700	3,100	2,100	5

Table 2. Summary of Low-Flow Parameters at Selected Stations, Lower Moose River Basin.

Name	Drainage Area (sq.mi.)	Selected Period of Record	Days	Minimum Consecutive Day Discharges for Selected Periods and for Indicated Average Recurrence Intervals in Years (discharges in cubic feet per second)									Graphical Presentation in Figures
				Annual Period Jan - Dec			Summer-Fall Period May - Oct			Winter Period Nov - Apr			
				2	5	10	2	5	10	2	5	10	
Abitibi River at Onakawana	10,600	1960-70	1	3500	<1000	<700	4000	1700	900	5000	3500	2700	6, 7, and 8
			7	6300	5000	4200	7100	5400	4500	7600	5800	4900	
			30	7600	6200	5400	8700	7000	6000	8500	6600	5700	
Mattagami River at Little Long Rapids	13,400	1964-70	1	1800	820	500e	5200	2000	1000e	2400	720	300e	9, 10, and 11
			7	4400	3900	3700e	6200	5600	5300e	5000	4400	4200e	
			30	5500	5000	4800e	7500	6800	6400e	6200	5400	5100e	
Moose River at Moose River	23,600	1960-70	1	6400	3700	2600	8300	4900	3400	6800	5200	4400	12, 13 and 14
			7	6500	4800	3900	9700	6000	4400	7200	5500	4600	
			30	7200	5600	5100	12500	7900	5800	7800	6100	5200	

Table 3. Summary of Consecutive Seven-Day Mean Discharges at Selected Stations, Lower Moose River Basin

Name	Drainage Area (sq.mi.)	Selected Period of Record	Streamflow Ranges (Starting date of seven-day period)			Graphical Presentation in Figure
			Minimum Flows (cfs)	Median Flows (cfs)	Maximum Flows (cfs)	
Abitibi River at Onakawana	10,600	1960-70	5,170 - 20,900 (Jan 1) (Apr 30)	8,780 - 40,100 (Mar 5) (Apr 30)	10,500 - 87,200 (Jan 1) (May 7)	15
Mattagami River at Little Long Rapids	13,400	1963-70	4,140 - 42,300 (Oct 1) (Apr 30)	6,040 - 68,400 (Jan 15) (Apr 23)	7,220 - 108,000 (Jan 22) (Apr 30)	16
Moose River at Moose River	23,600	1960-70	4,200 - 57,000 (Sep 3) (Apr 30)	7,830 - 137,000 (Mar 12) (Apr 7)	11,100 - 239,000 (Mar 12) (Apr 14)	17

Table 4. Comparison between Mean Daily and Seven-Day Moving Average Discharges, Abitibi River at Onakawana, 1960-1970.
Note: Data extracted from Figure 2.

Percentage of Time Discharge was Equalled or Exceeded	Discharges (cubic feet per second)	
	Mean Daily	Seven-Day Moving Avg.
50	11,000	11,000
80	8,200	8,400
90	7,000	7,500
95	6,100	6,700
98	5,100	5,600
99	4,200	5,300
99.9	1,500	4,700
99.99	700	4,500

Table 5. Ground Water Levels, Onakawana Area, August 1972.

Date	Sampling Site	Formation and Bottom Depth	(ft.)	Depth to Water B.G.L. (ft.)	Depth of Hole B.G.L. (ft.)	Estimated Ground Elevation A.S.L. (ft.)	Estimated Water Elevation A.S.L. (ft.)
August 9, 1972	W-21	Upper lignite bed	48.2	10.28	30	160	150
	W-21	Lower lignite bed	66.9	10.30	60	160	150
August 12, 1972	W-15	Muskeg	3	1.48	3	160	160
August 13, 1972	W-16	Sandy till		6.81	10	160	153
	W-19	Interglacial sand and gravel	60	20.80	60	160	139
August 14, 1972	W-20	Cretaceous sand	100	29.53	100	160	130

Note: On August 12, 1972, the water level in the Abitibi River was 123 feet at approximately 11 a.m., the water level in the flooded lignite pit near sampling site W-21 was 131 feet, and the one in the pit near the Abitibi River was 129 feet above mean sea level.

Table 6. Summary of Permeability Tests, Onakawana Area, 1972.

Well No.	Formation	Saturated Thickness of Formation (ft.)	Static Water Level (B.G.L.) (ft.)	Coefficient of Permeability (gpd/ft.^{2})	Coefficient of Transmissibility (gpd/ft.)	Permissible Drawdown (ft.)	Estimated Well Yield* (gpm)
W-21	Upper lignite bed	23.4	10.28	9.4	222	24	4.1
W-21	Lower lignite bed	14.1	10.30	0.3	4.25	40	0.15
W-15	Muskeg	0.45	1.48	32.2	14.5	-	-
W-19	Interglacial sand and gravel	20	20.80	10.8	215	35	4.7
W-20	Cretaceous sand	10	29.53	8.8	87.9	50	2.9

* As the aquifers are confined, the coefficient of storage was assumed to be 0.0005. The estimated well yields were based on continuous pumpage for a 12-hour duration and a well with a six-inch casing.

Table 7. Estimate of Ground Water Seepage per Foot of Pit Length, Onakawana Area.

Formation	Mean Coefficient of Transmissibility (gpd/ft.)	Estimated Coefficient of Storage	Average Drawdown (ft.)	Estimated Seepage Rate per Foot at Selected Times Since Start of Water-Table Drop (gpm)			
				1 Hour	1 Day	7 Days	30 Days
Muskeg	32.2	0.20	2.2	0.026	0.005	0.002	0.001
Interglacial sand and gravel	215	0.001	40	0.089	0.018	0.007	0.003
Upper lignite bed	222	0.0005	50	0.080	0.016	0.006	0.003
Lower lignite bed	4.25	0.0005	80	0.018	0.004	0.001	0.001
Total	-	-	-	0.213	0.043	0.016	0.008

Table 8. Chemical and Physical Analyses, Moose River Basin.

SAMPLING SITE	SOURCE AND LOCATION	DATE SAMPLED	pH	ALKALINITY AS PPM $CaCO_3$	HARDNESS AS PPM $CaCO_3$	TOTAL DISSOLVED SOLIDS IN PPM	SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C)	COLOR	TURBIDITY (JTU)	TANINS (PPM)	MINERAL CONSTITUENTS IN PARTS PER MILLION (PPM): Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Boron (B)	Nitrate (NO_3)	Total Kjeldahl	Total Phosphorus (P)
S-7	Missinabi River at Mattice 4LJ-1 (Con't)	23/06/71	-	46	-	-	-	-	-	2	3.1	0.50	17	3	1	-	-	-	2	-	-	0.48	0.016
		17/08/71	-	74	-	-	-	-	-	1.0	4.2	0.35	26	4	1	-	-	-	1	-	0.01	0.43	0.012
		29/10/71	-	74	-	-	-	-	-	1.0	5.2	0.50	25	6	1	-	-	-	1	-	<0.01	0.53	0.020
		23/02/72	-	74	-	-	-	-	-	0.5	5.3	0.30	25	5	1	-	-	-	2	-	0.12	0.42	0.010
S-8	Moose River at Moose River 4LG-2	20/10/70	-	63	-	-	-	-	-	6.0	-	0.60	24	3	2	-	-	11	3	-	<0.01	0.50	0.026
		19/01/71	-	12	-	-	-	-	-	0.5	3.0	0.15	8	2	4	-	-	5	8	-	-	0.38	0.028
		18/05/71	-	-	-	-	-	-	-	2.5	4.2	2.6	26	3	1	-	-	<5	1	-	-	0.65	0.12
		13/07/71	-	65	-	-	-	-	-	1.5	3.1	0.45	22	5	2	-	-	10	2	-	<0.01	0.40	0.022
		04/10/71	-	60	-	-	-	-	-	2.0	4.7	1.8	22	4	1	-	-	<5	1	-	0.01	0.60	0.052
S-9	Mattagami River	27/09/72	8.0	-	-	150	-	100	6	-	-	-	-	-	-	-	-	10	-	-	<0.01	0.70	-
S-10	Moose River at Abatabi River	30/09/71	-	-	-	-	-	-	-	-	3.7	1.0	-	-	-	-	-	5	-	-	0.01	0.76	0.096
		24/03/72	-	83	-	-	-	-	-	3	5.8	1.1	30	6	4	-	-	21	5	-	<0.04	0.40	0.028
S-11	Medicine Creek at Railroad	25/07/71	-	32	-	-	78	350	4	5.0	-	1.4	17	4	2	<0.1	-	10	4	-	0.02	0.82	0.049
		26/09/72	7.1	22	-	110	-	>250	3	-	-	-	-	-	-	-	-	<5	-	-	<0.01	0.90	0.25
S-12	Onakawana River at Railroad	25/07/72	-	68	-	-	134	100	3	1.5	-	0.40	26	4	1	<0.1	-	<5	2	-	<0.01	0.54	0.021
		25/09/72	7.6	124	-	190	-	100	3	-	-	-	-	-	-	-	-	<5	-	-	<0.01	1.7	0.070
S-13	Opastica River	24/03/72	-	90	-	-	160	-	-	0.5	3.4	0.15	30	5	1	-	-	8	2	-	0.12	0.33	0.11
W-15	Muskeg (Augered hole 3 feet deep)	11/08/72	7.0	188	200	240	339	125	40	1	3.0	0.05	61	13	3	0.6	0	10	1	<0.02	0.02	-	0.080
W-16	Dug Well	13/08/72	7.1	348	368	380	643	5	12	0	-	7.6	109	23	3	0.3	348	34	2	-	<0.01	-	0.005
W-17	Dug Well	25/07/72	-	194	-	-	-	-	-	0.5	-	0.8	63	12	1	0.6	-	<5	1	-	0.02	-	0.02
W-18	Drill Hole	25/07/72	7.6	405	376	480	687	125	15	-	3.0	1.9	128	13	16	1.8	405	8	4	-	<0.01	-	0.01
W-19	Well 60 feet deep	14/08/72	7.6	201	208	280	480	85	80	0.5	6.0	0.15	54	18	15	1.9	-	22	18	-	0.01	-	0.014
W-20	Well 100 feet deep	13/08/72	7.3	295	376	520	853	5	10	0.5	-	0.35	101	30	38	2.5	295	62	55	-	<0.01	-	0.008
W-21	Drill Hole 30 feet	11/08/72	7.5	376	172	440	617	70	50	1.0	8.5	4.4	37	19	95	4.4	376	9	11	-	0.01	-	0.40
W-21	Drill Hole 60 feet	11/08/72	7.8	453	116	560	806	85	0.20	1.0	13.0	4.1	31	10	181	4.1	453	12	29	-	0.03	-	0.20

Table 8. (Continued)

SAMPLING SITE	SOURCE AND LOCATION	DATE SAMPLED	pH	ALKALINITY AS PPM $CaCO_3$	HARDNESS AS PPM $CaCO_3$	TOTAL DISSOLVED SOLIDS IN PPM	SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C)	COLOR	TURBIDITY (JTU)	TANINS (PPM)	MINERAL CONSTITUENTS IN PARTS PER MILLION (PPM): Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Boron (B)	Nitrate (NO_3)	Total Kjeldahl	Total Phosphorus (P)
S-1	Abitibi River at Onakawana 4ME-3	21/10/70	-	63	-	-	-	-	-	3.5	-	1.3	22	5	2	-	-	17	2	-	0.01	0.58	0.052
		20/01/70	-	12	-	-	-	-	-	0.5	4.7	1.3	8	2	4	-	-	5	8	-	-	0.40	0.040
		19/05/71	-	56	-	-	-	-	-	2.5	4.3	2.5	22	2	1	0.6	-	5	1	-	-	0.75	0.090
		14/07/71	-	59	-	-	-	-	-	1.0	4.7	1.0	21	4	2	-	-	<5	1	-	0.01	0.36	0.034
		05/10/71	-	59	-	-	-	-	-	1.0	6.3	2.3	22	5	2	-	-	11	1	-	<0.01	0.47	0.048
		14/03/72	-	71	-	-	-	-	-	1.0	7.9	4.0	26	7	3	-	-	25	2	-	0.14	0.64	0.078
		25/07/72	-	58	-	-	128	150	8	1.5	-	0.85	22	6	1	0.5	-	14	3	-	0.04	0.58	0.035
		27/09/72	8.0	60	-	140	-	150	40	-	-	-	-	-	-	-	-	22	-	-	0.08	1.1	0.13
L-2	Flooded Lignite Pit #1	25/07/72	-	166	-	-	509	15	78	0.5	-	0.15	56	15	30	2.7	-	81	16	-	<0.01	0.28	0.009
		27/09/72	8.0	180	-	380	-	15	6	-	-	-	-	-	-	-	-	94	-	-	<0.01	0.33	0.014
		09/08/72	8.2	178	208	330	572	<5	4	0	-	0.10	56	16	32	3.0	178	82	17	-	<0.01	-	0.005
L-3	Flooded Lignite Pit #2	09/08/72	7.9	276	240	590	969	5	4	0	-	0.25	54	25	115	6.7	276	113	86	-	0.03	-	0.013
S-4	Groundhog River	29/09/72	-	53	-	-	-	-	-	2	3.7	1.0	19	3	1	-	-	<5	<1	-	<0.01	0.22	0.012
S-5	Kapuskasing River at Kapuskasing 4LF-1	08/07/70	-	67	-	-	-	-	-	2.5	-	0.70	24	3	3	-	-	17	3	-	<0.01	0.69	0.020
		20/09/70	-	60	-	-	-	-	-	2.5	-	1.6	24	6	4	-	-	25	6	-	<0.01	1.0	0.095
		15/09/70	-	59	-	-	-	-	-	40.0	-	0.70	24	5	2	-	-	21	5	-	<0.01	0.77	0.072
		27/10/70	-	55	-	-	-	-	-	87.0	-	0.95	30	8	4	-	-	26	9	-	<0.01	1.0	0.16
		16/12/70	-	60	-	-	-	-	-	18	5.3	0.75	26	6	2	0.9	-	12	2	-	<0.01	0.38	0.056
		29/04/71	-	44	-	-	-	-	-	8	4.4	0.75	18	3	7	-	-	5	2	-	-	0.70	0.040
		17/08/71	-	62	-	-	-	-	-	12	5.3	0.60	27	6	2	-	-	29	2	-	0.01	1.2	0.046
		29/10/71	-	64	-	-	-	-	-	10	5.3	1.0	26	7	3	-	-	20	2	-	<0.01	0.07	0.058
		23/02/72	-	74	-	-	-	-	-	10	5.3	0.45	30	8	4	-	-	23	5	-	0.01	0.68	0.080
S-6	Little Abitibi River at Pierre Lake	08/06/71	-	44	-	-	90	70	25	0.5	3.4	0.30	16	2	0.8	-	-	8	1	-	0.02	0.27	0.014
		22/06/71	-	-	-	-	92	40	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		02/07/71	-	45	-	-	95	40	20	1	2.9	0.25	14	4	0.8	-	-	8	1	-	0.02	0.28	0.020
		19/07/71	-	-	-	-	100	50	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		29/07/71	-	-	-	-	95	40	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		17/08/71	-	46	-	-	110	70	15	0.5	2.3	0.25	16	3	1	-	-	7	1	-	<0.01	0.40	0.022
		27/08/71	-	-	-	-	97	70	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		30/09/71	-	46	-	-	100	85	20	0.5	<.1	0.35	15	3	1	-	-	<5	1	-	<0.01	0.35	0.021
		24/03/72	-	49	-	-	121	-	-	1	3.1	0.15	17	4	1	-	-	14	1	-	0.02	0.32	0.012
S-7	Missinabi River at Mattice 4LJ-1	08/08/70	-	64	-	-	-	-	-	2.0	-	0.45	20	6	1	-	-	12	1	-	<0.01	0.85	0.023
		19/08/70	-	58	-	-	-	-	-	1.6	-	0.30	24	1	1	-	-	9	1	-	<0.01	0.37	0.017
		15/09/70	-	74	-	-	-	-	-	3.0	-	0.55	28	3	1	-	-	5	1	-	<0.01	0.32	0.032
		27/10/70	-	72	-	-	-	-	-	2.5	-	1.25	26	5	1	-	-	12	2	-	<0.01	0.61	0.053
		16/12/70	-	70	-	-	-	-	-	2.5	4.9	0.30	24	5	1	-	-	<5	1	-	-	0.50	0.012
		30/04/71	-	58	-	-	-	-	-	1.5	3.9	0.60	21	4	1	-	-	-	1	-	-	0.56	0.024

Table 9. Heavy Metal Analyses, Lower Moose River Basin

SAMPLING SITE	SOURCE AND LOCATION	DATE SAMPLED	CADMIUM Cd (PPM)	COBALT Co (PPM)	COPPER Cu (PPM)	LEAD Pb (PPM)	MANGANESE Mn (PPM)	MERCURY Hg (PPM)	NICKEL Ni (PPM)	ZINC Zn (PPM)
L 2	FLOODED LIGNITE PIT	25/7/72	<0.01	<0.03	<0.03	<0.06	—	—	0.06	<0.01
S4	GROUNDHOG RIVER	29/9/71	<0.02	<0.06	<0.06	—	<0.04	<0.2	0.13	0.04
S6	LITTLE ABITIBI RIVER AT PIERRE LAKE	24/3/72	<0.002	<0.006	<0.005	<0.010	<0.005	<0.6	<0.005	0.010
S7	MISSINAIBI RIVER AT MATTICE	1/10/71	<0.04	<0.12	<0.12	—	<0.08	<0.2	0.10	0.08
S10	MOOSE RIVER AT THE ABITIBI RIVER	24/3/72	<0.002	<0.006	0.014	<0.010	0.027	<0.6	<0.005	0.013
S10	MOOSE RIVER AT THE ABITIBI RIVER	2/7/71	<0.02	<0.06	<0.06	—	<0.04	<0.2	0.13	0.05
S10	MOOSE RIVER AT THE ABITIBI RIVER	30/9/71	0.04	<0.12	<0.12	—	0.10	<0.2	0.20	0.08
S13	OPASASTIKA RIVER	24/3/72	<0.002	<0.006	0.010	<0.010	0.010	<0.6	<0.005	<0.010

Table 10. Temperature Measurements on the Abitibi River at Onakawana.

Date	Air Temperature (^{o}F)	Water Temperature (^{o}F)
Jan 19, 1961	-10	33
Feb 14, 1961	6	33
Mar 14, 1961	29	33
Apr 11, 1961	38	33
May 8, 1961	55	41
Jul 24, 1961	70	68
Sep 24, 1961	58	57
Nov 7, 1961	38	38
Jul 23, 1962	60	65
Nov 3, 1962	26	36
Nov 4, 1962	32	37
Jan 8, 1963	28	33
Feb 12, 1963	23	32
Mar 12, 1963	5	32
Apr 27, 1963	50	32
Apr 28, 1963	49	32
Jun 26, 1963	74	63
Sep 20, 1963	60	58
Sep 21, 1963	50	54
Sep 22, 1963	47	52
Feb 20, 1964	11	32
Apr 9, 1964	36	32
May 23, 1964	70	55
May 24, 1964	50	55
Jul 21, 1964	79	68
May 10, 1965	36	37
Sep 14, 1965	66	55
May 26, 1967	62	45
Jul 23, 1967	74	73
Jul 6, 1968	67	60
Jul 16, 1969	78	74
Oct 20, 1970	48	49

Note: Data from Environment Canada, Inland Waters Branch.

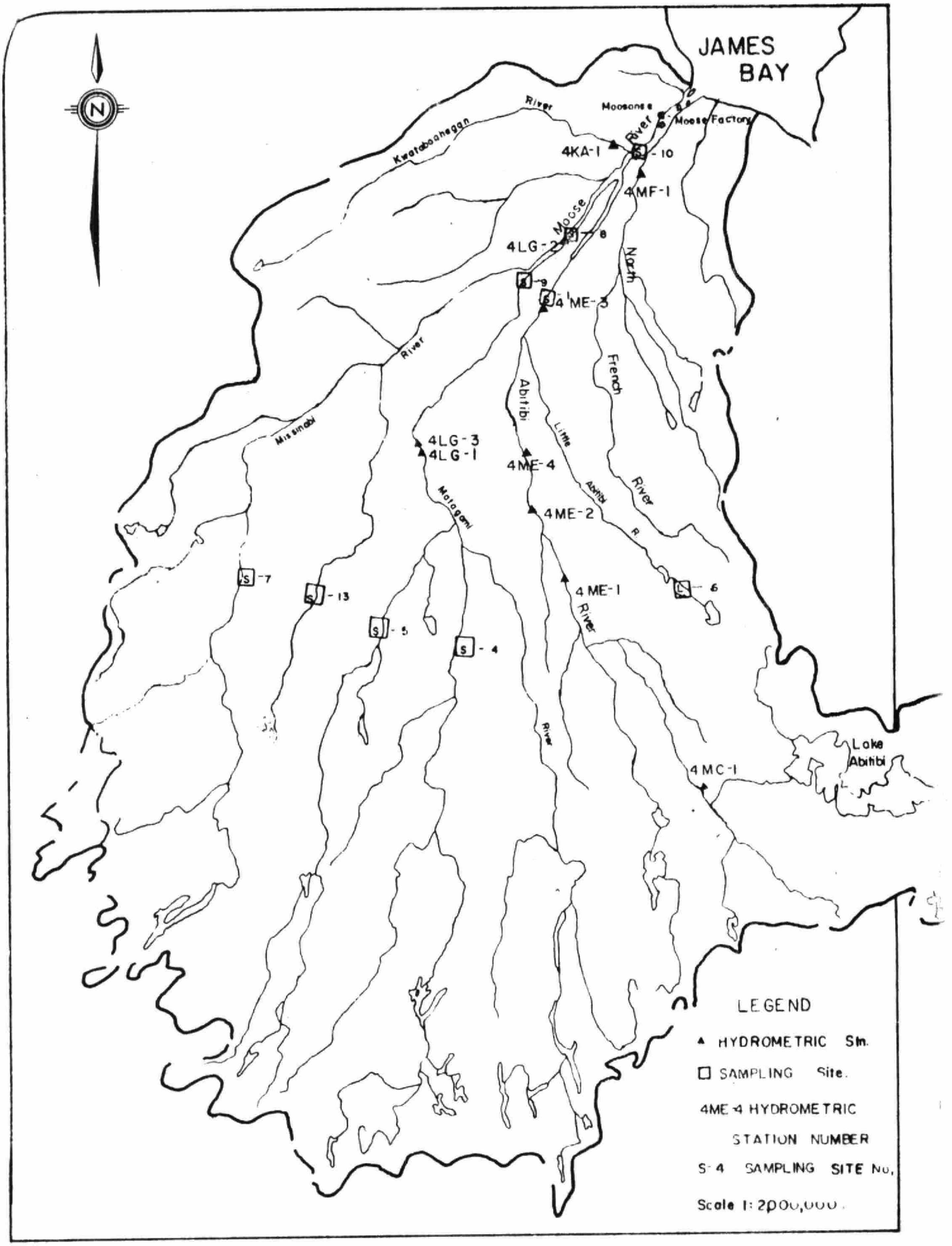

Figure 1. MOOSE RIVER BASIN, LOCATION OF HYDROMETRIC STATIONS AND WATER QUALITY SAMPLING SITES.

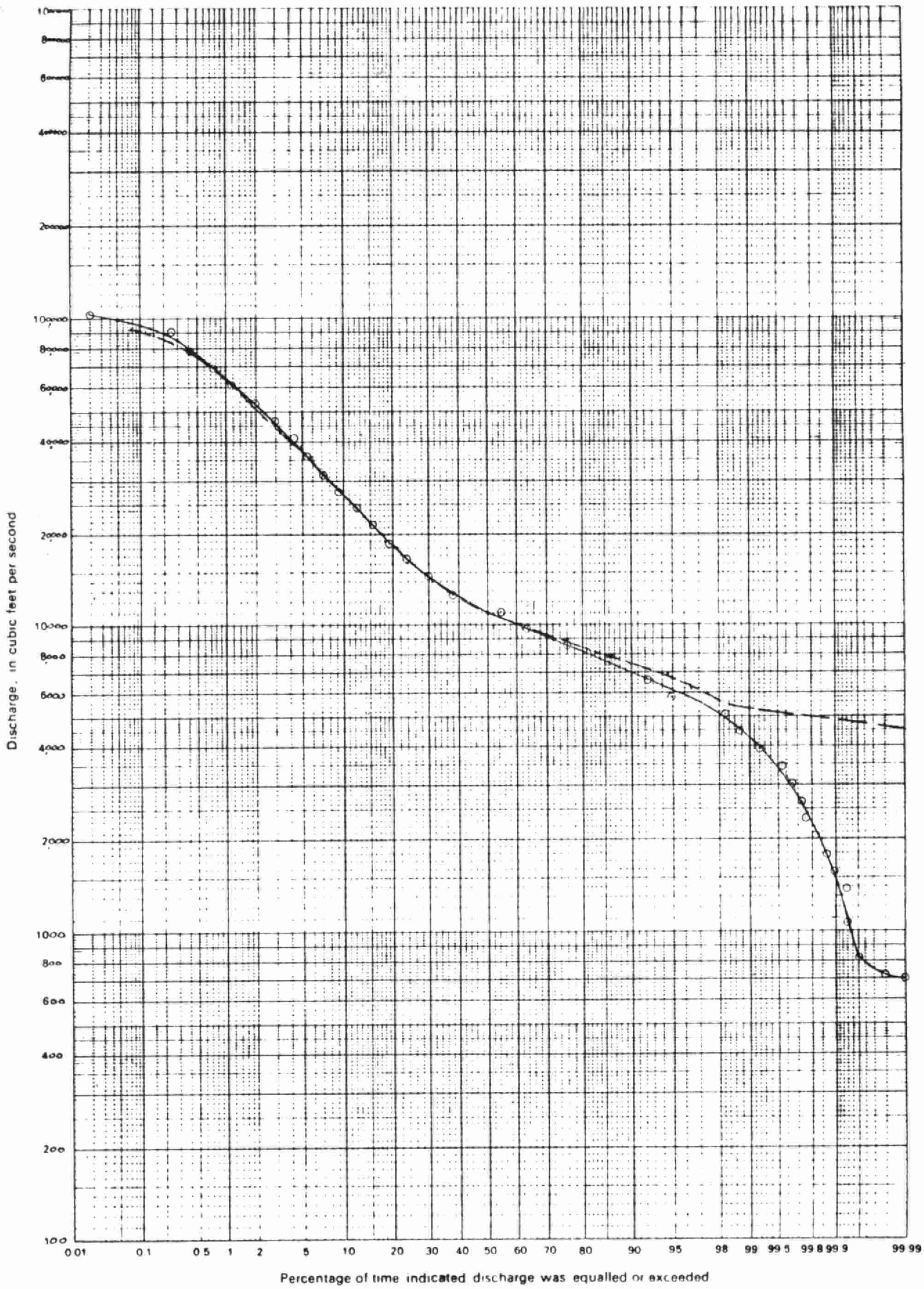

Figure 2. Duration curves of daily and seven-day moving average flows, of Abitibi River at Onakawana, at Station 04ME003, 1960-1970. (drainage area: 10,600 square miles.

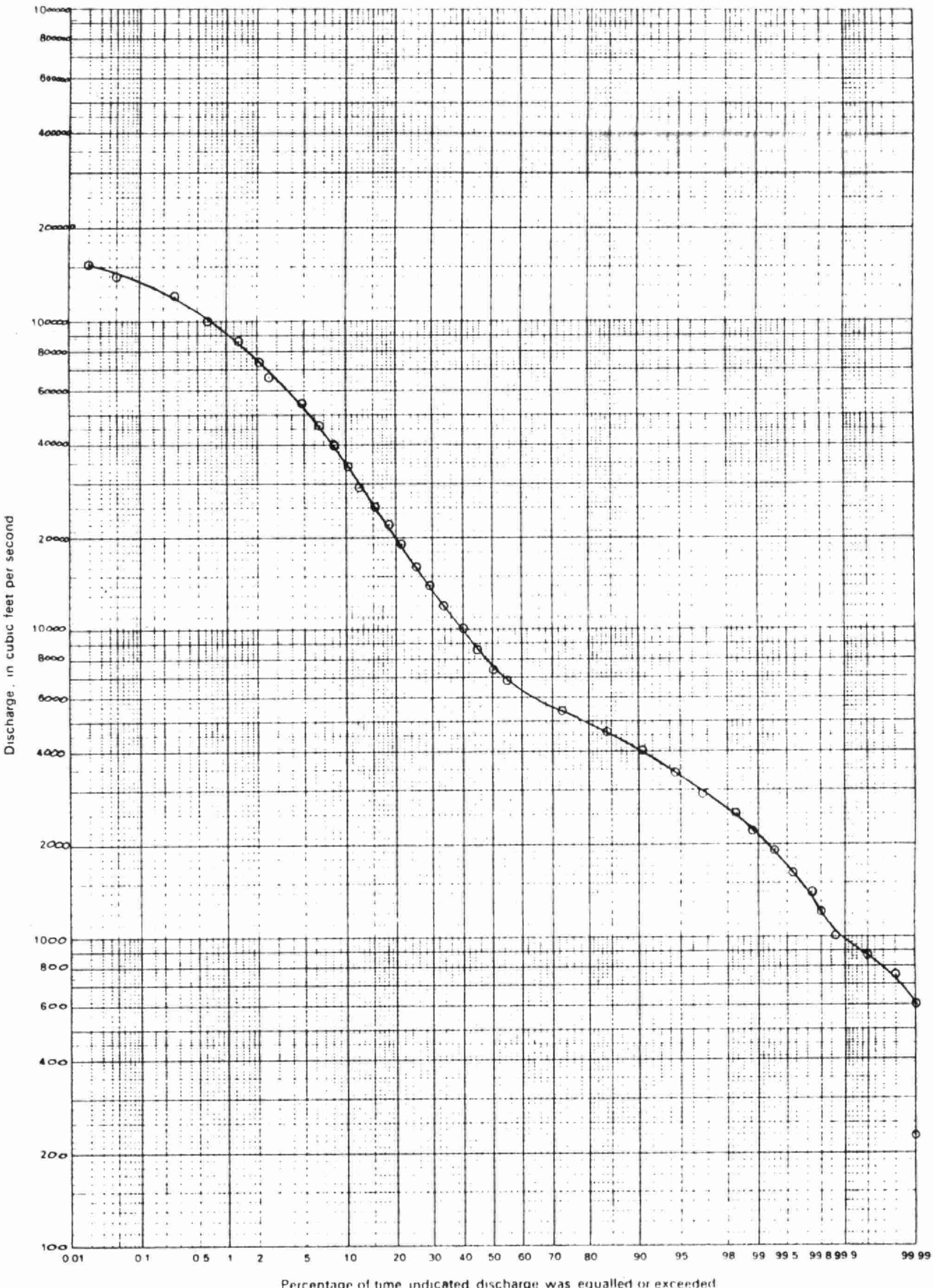

Figure 3. Duration curve of daily flows of the Mattagami River at Smoky Falls, at station 04LG001, for the period 1927-1962. (drainage area: 13,400 square miles)

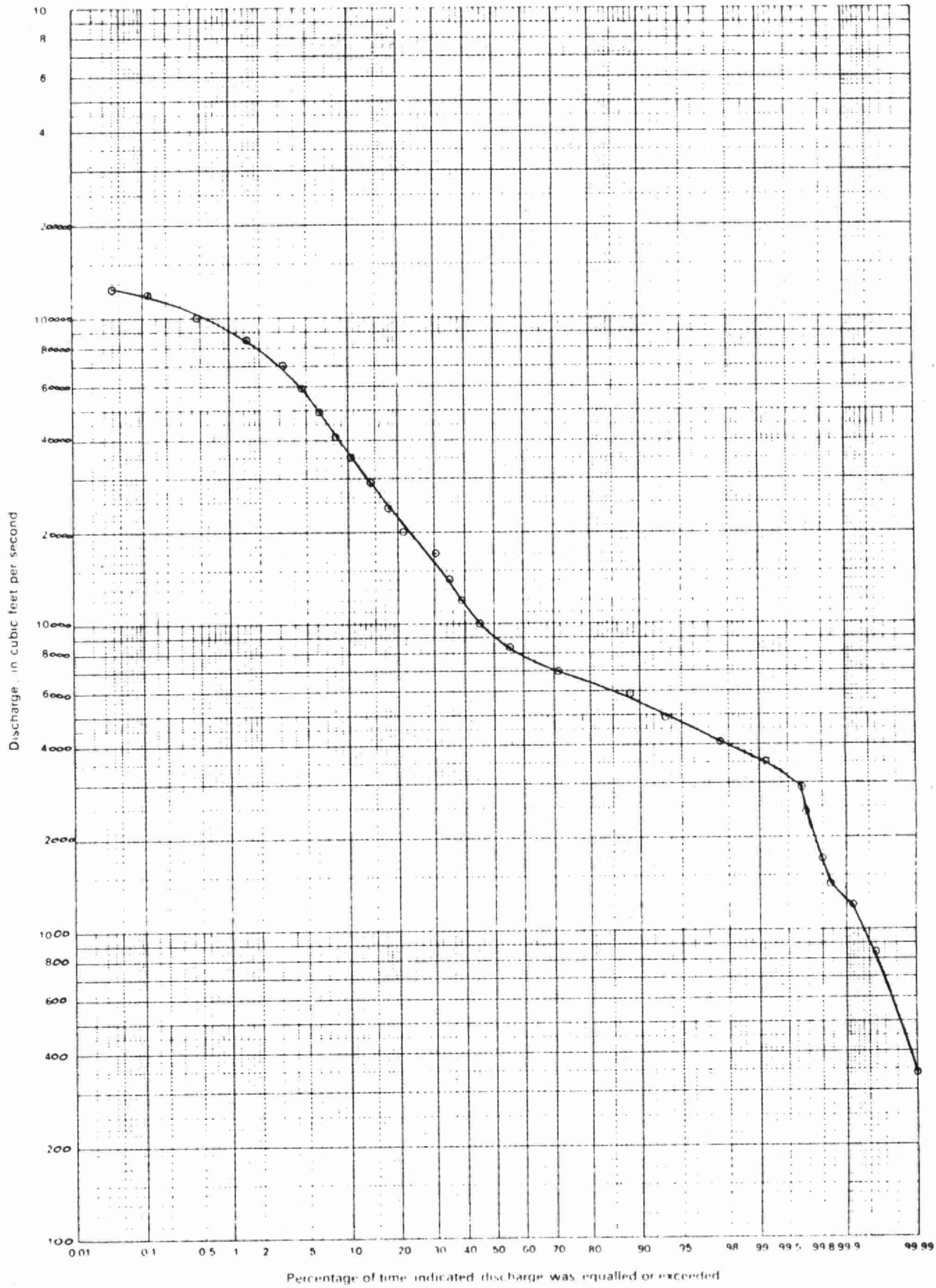

Figure 4. Duration curve of daily flows of the Mattagami River at Little Long Rapids, at station 04LG003, for the period 1964-1970. (drainage area: 13,400 square miles)

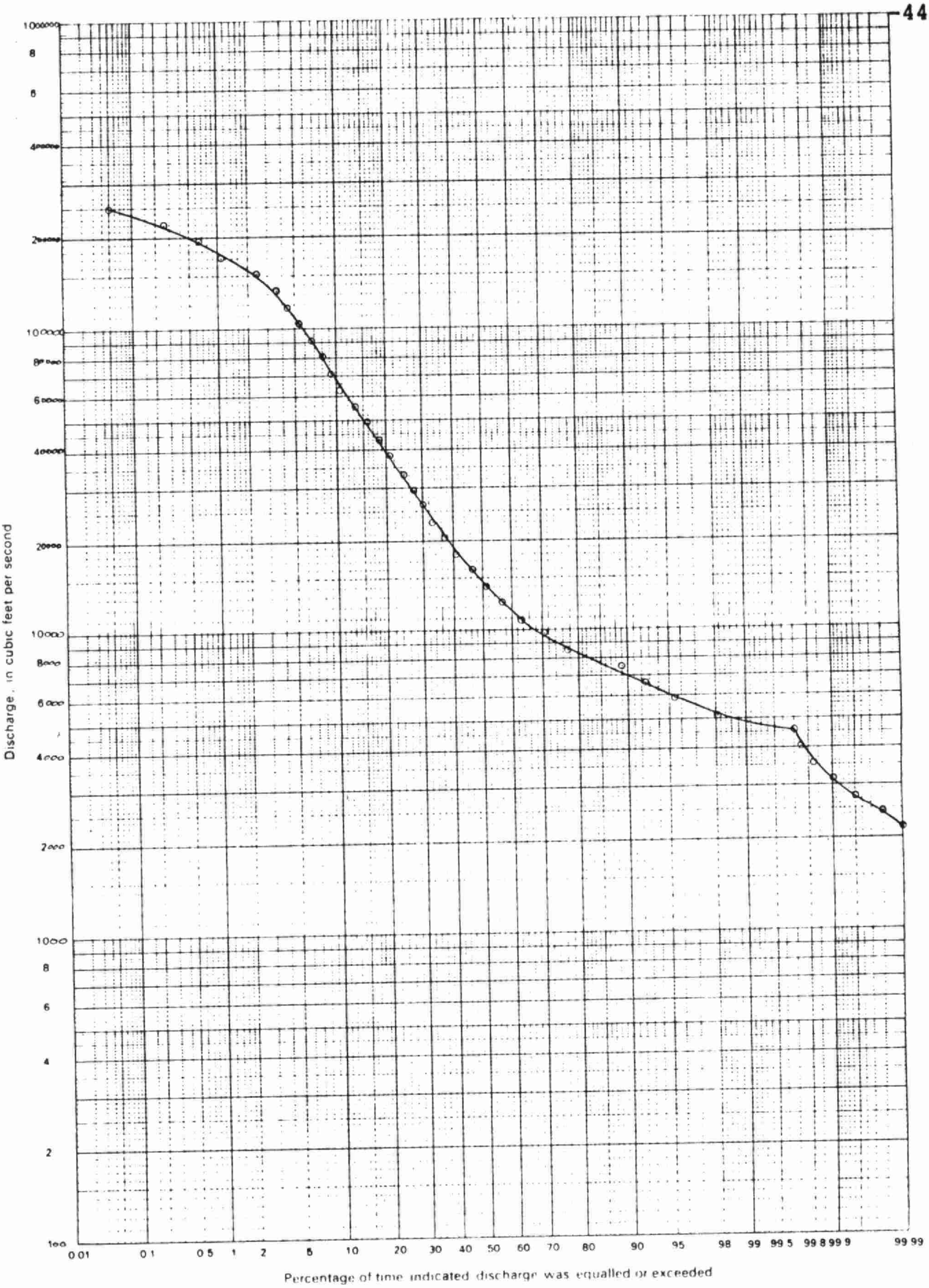

Figure 5. Duration curve of daily flows of the Moose River at Moose River, at Station 04LG002, for the period 1960-1970. (drainage area: 23,600 square miles)

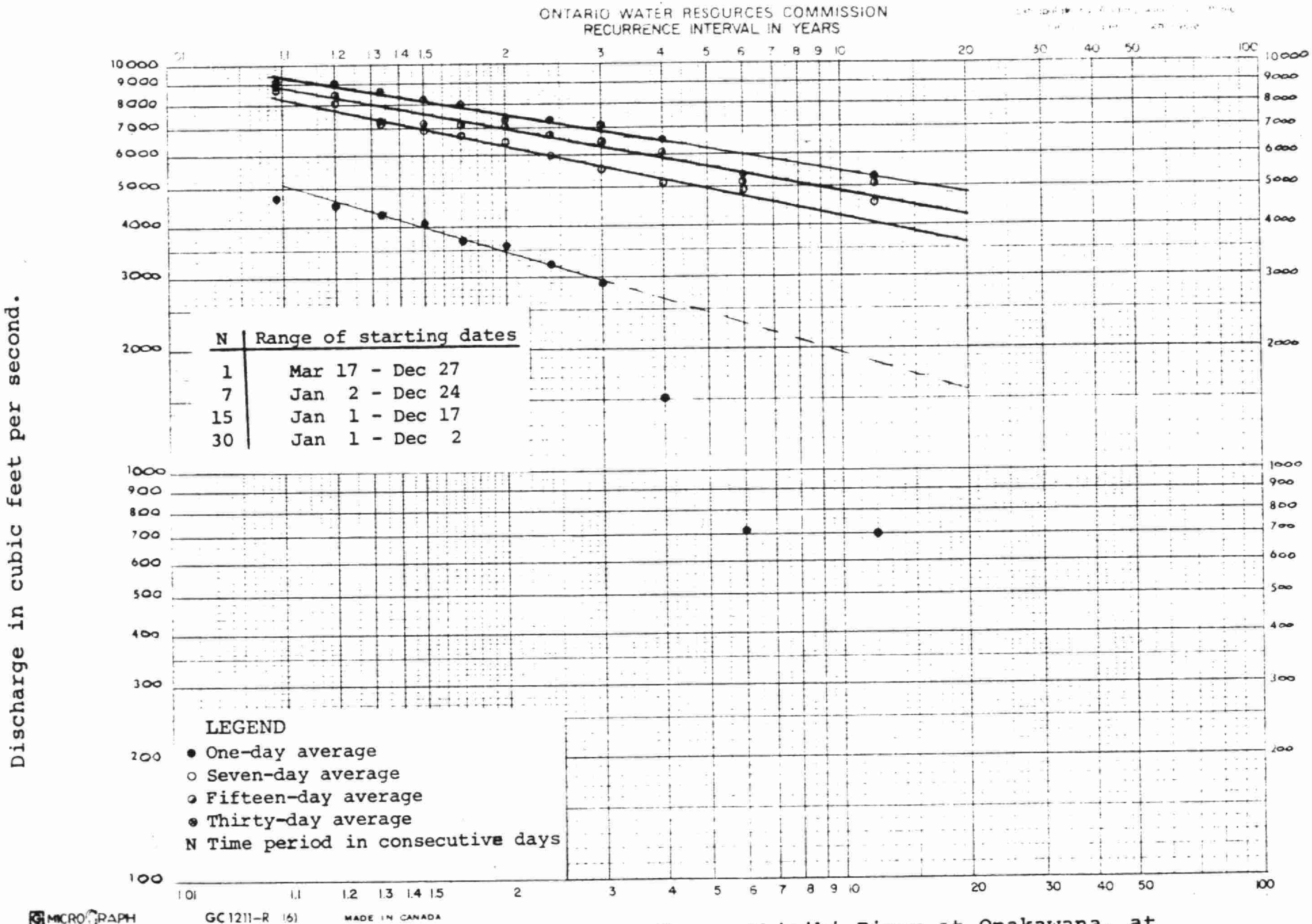

Figure 6. Frequency curves of low flows, Abitibi River at Onakawana, at Station 04ME003, January-December, 1960-1970.

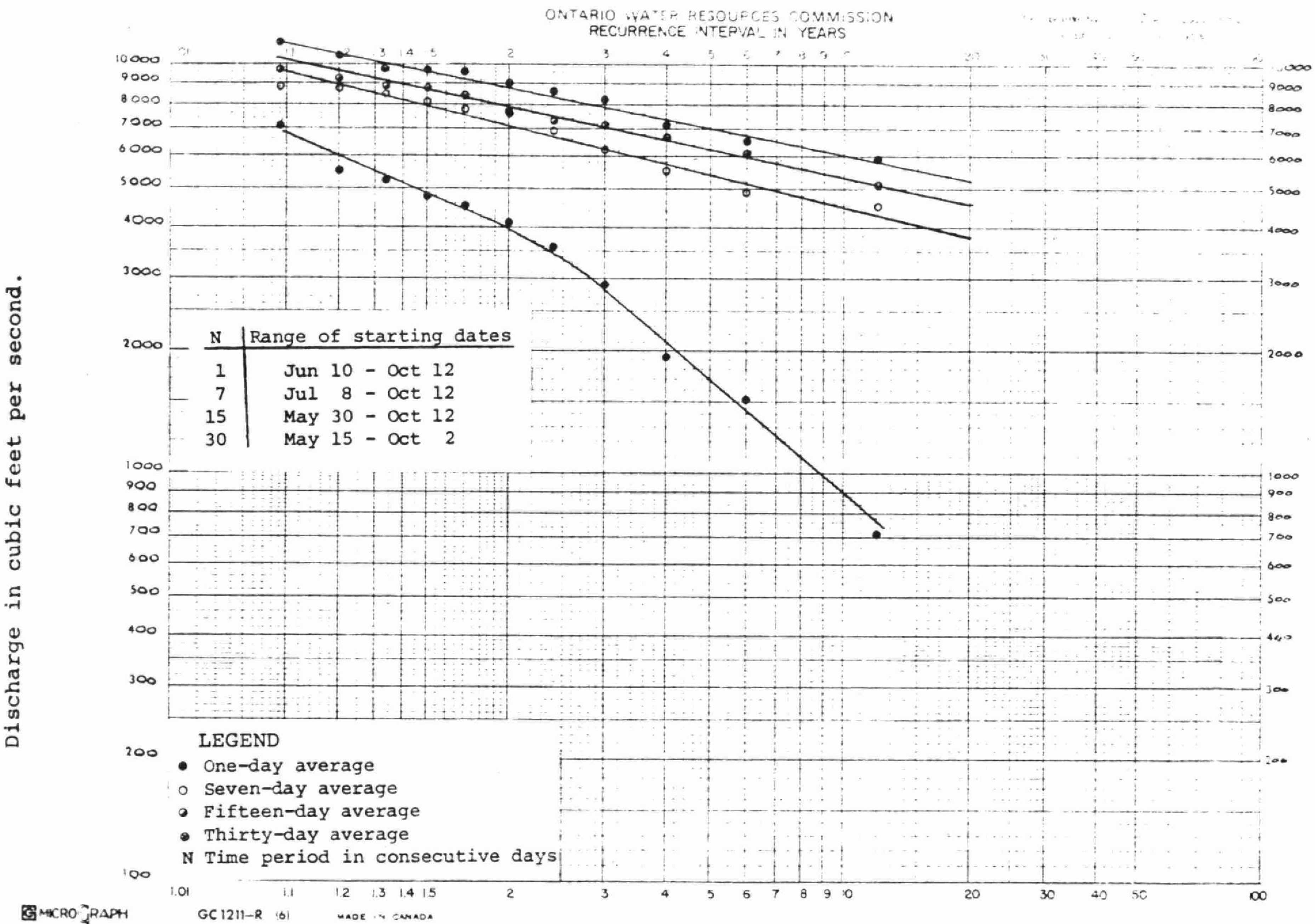

Figure 7. Frequency curves of low flows, Abitibi River at Onakawana, at Station 04ME003, May-October, 1960-1970.

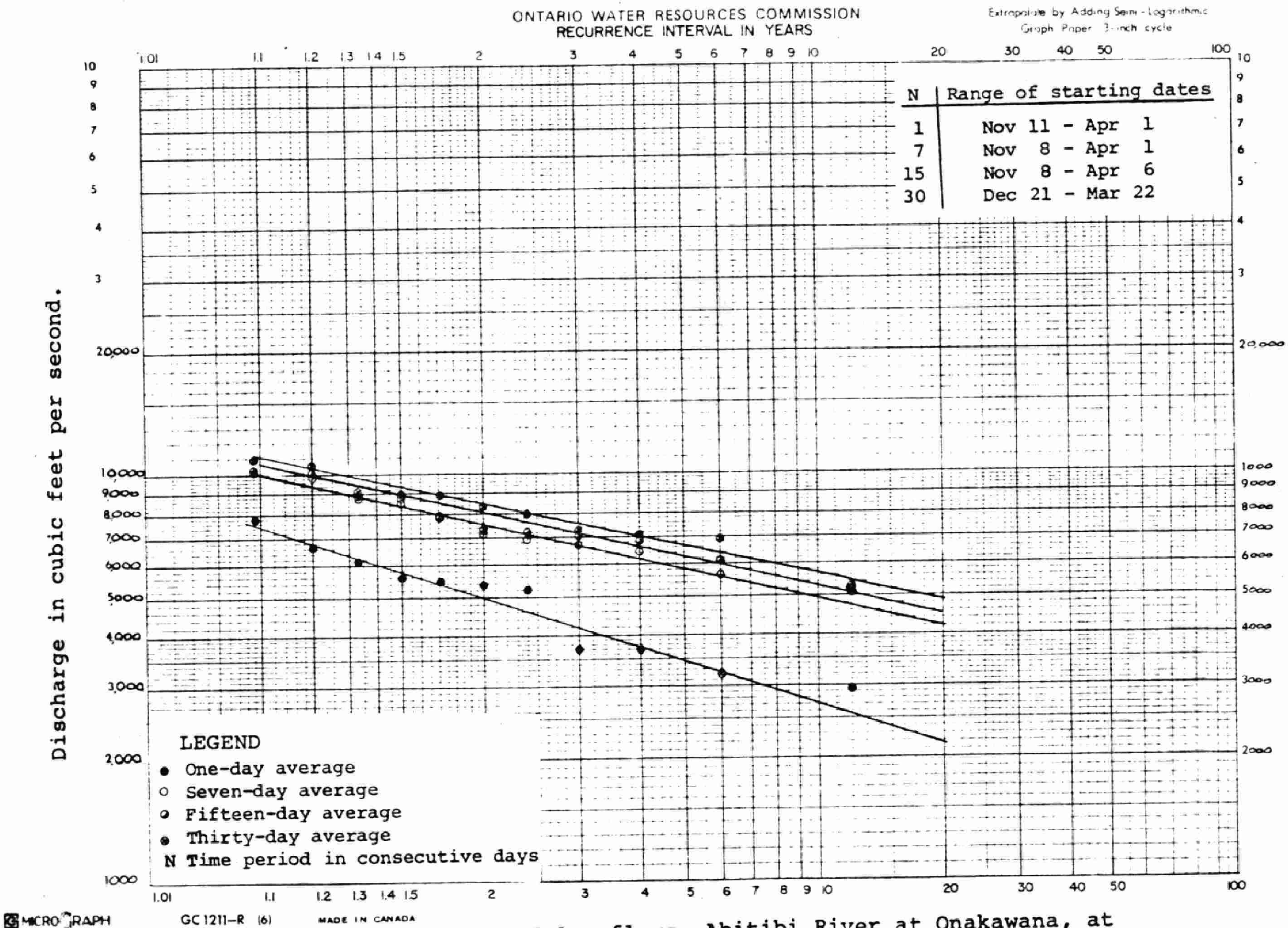

Figure 8. Frequency curves of low flows, Abitibi River at Onakawana, at Station 04ME003, November-April, 1959-1970.

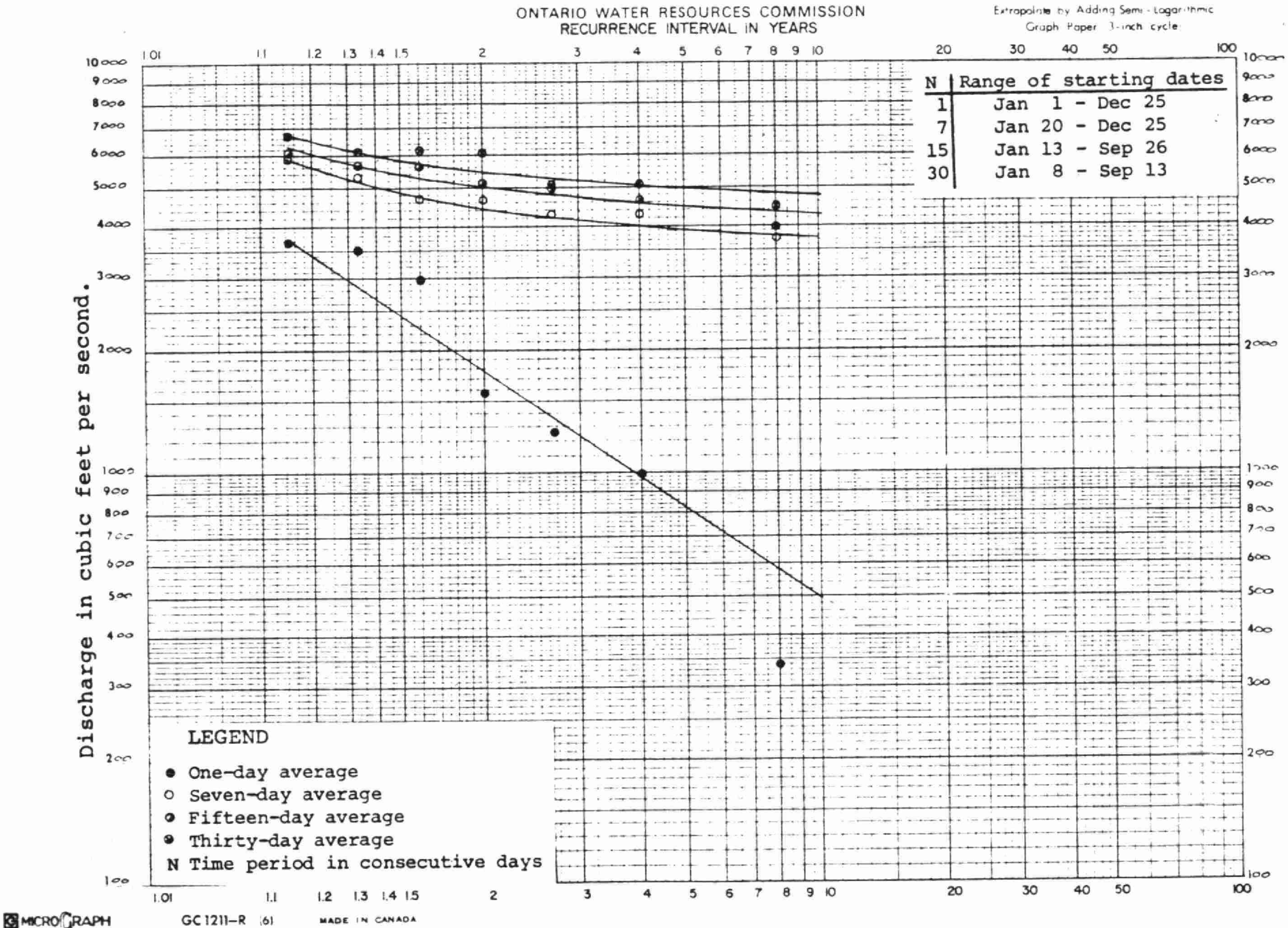

Figure 9. Frequency curves of low flows, Mattagami River at Little Long Rapids, at station 04LG002, January-December, 1964-1970.

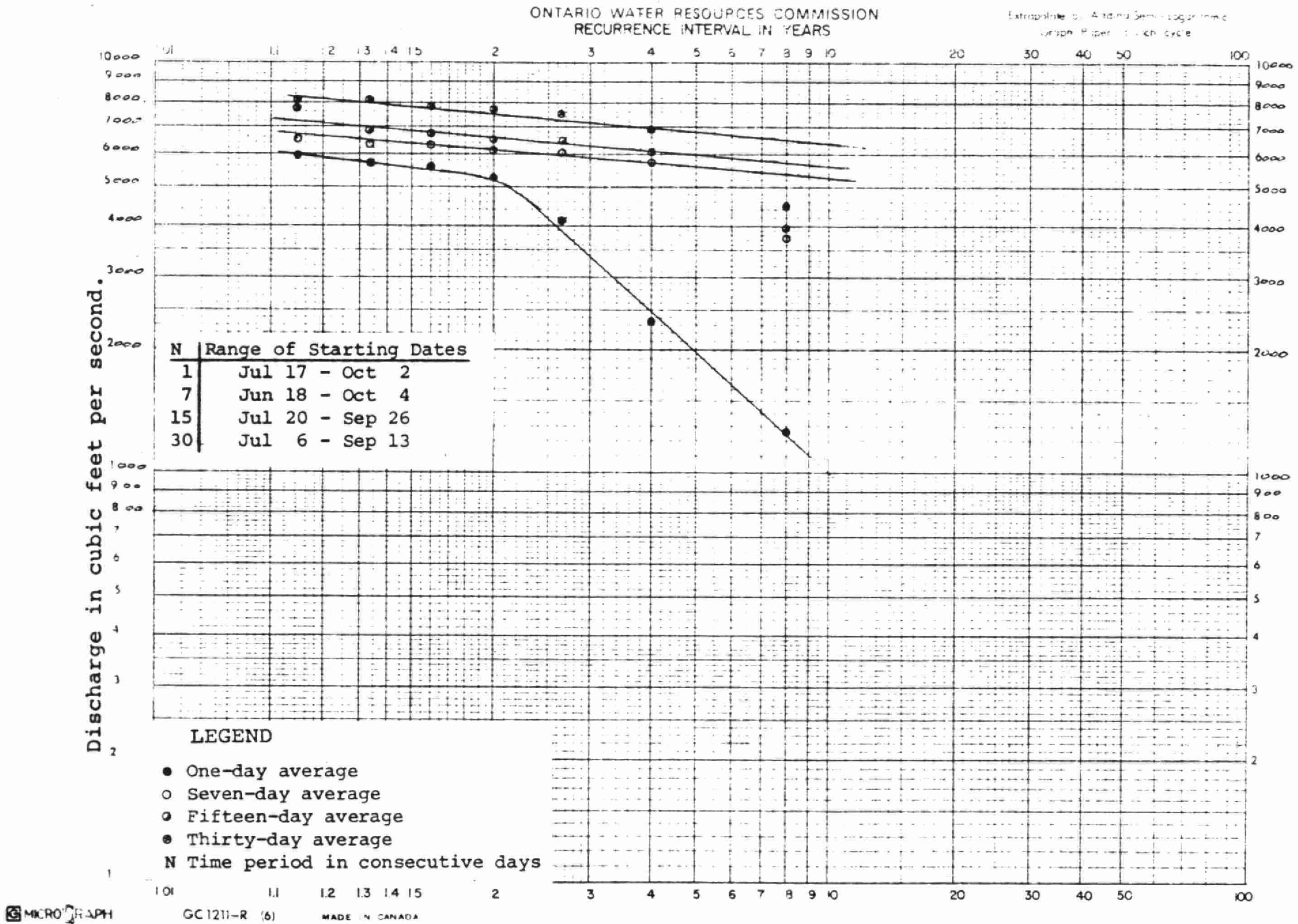

Figure 10. Frequency curves of low flows, Mattagami River at Little Long Rapids, at station 04LG003, May-October, 1964-1970.

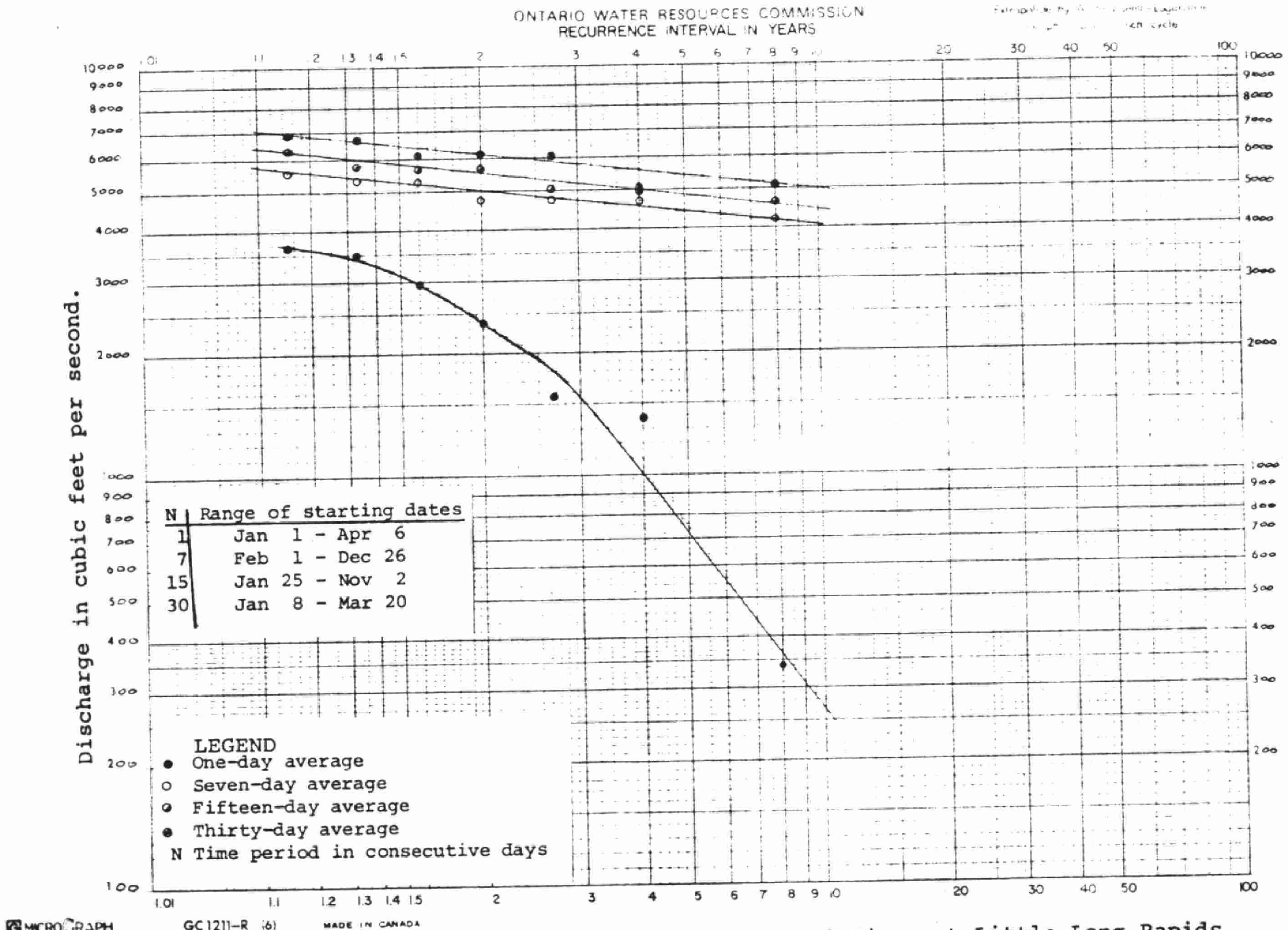

Figure 11. Frequency curves of low flows, Mattagami River at Little Long Rapids, at station 04LG003, November-April, 1963-1970.

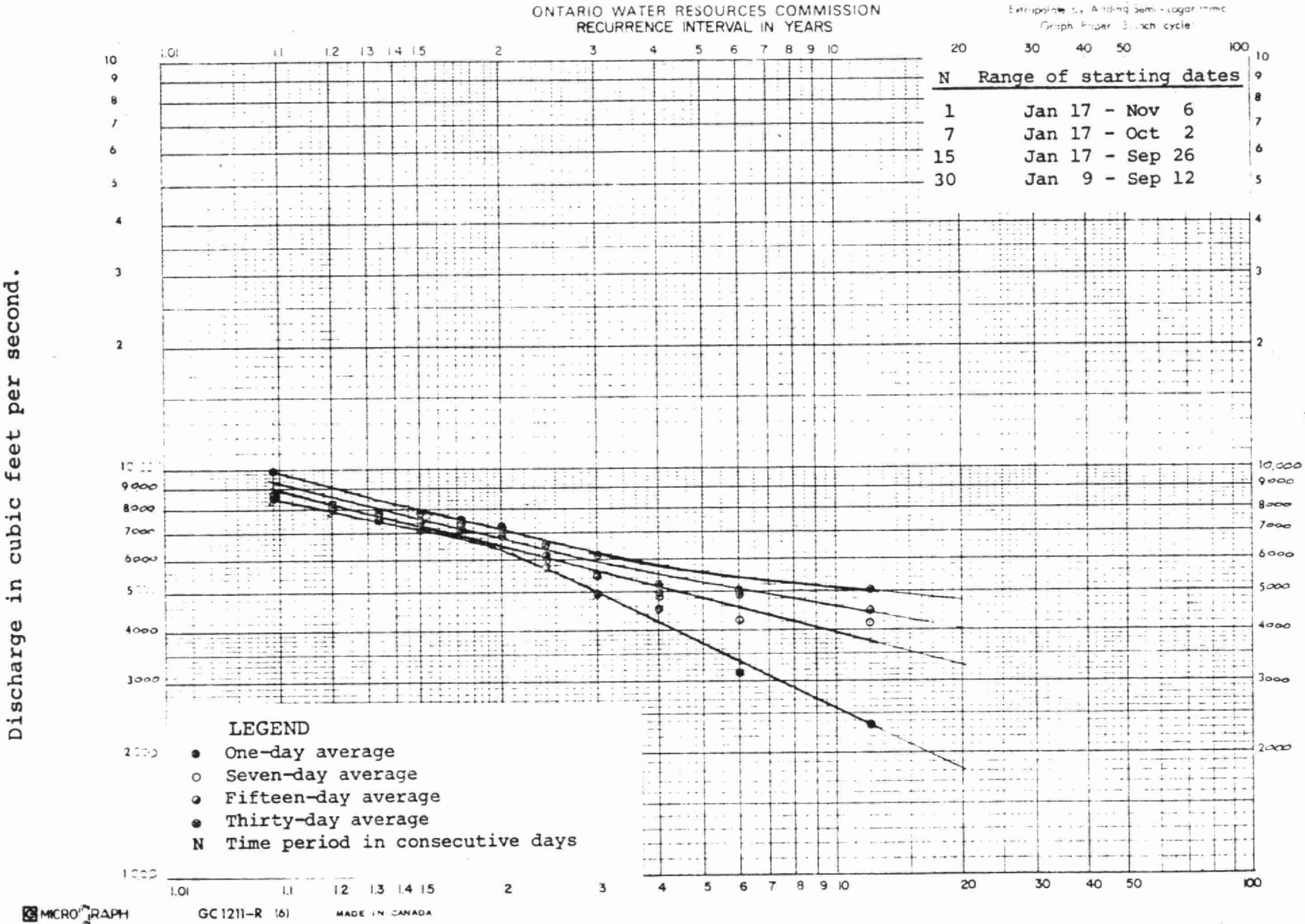

Figure 12. Frequency curves of low flows, Moose River at Moose River, at Station 04LG002, January-December, 1960-1970.

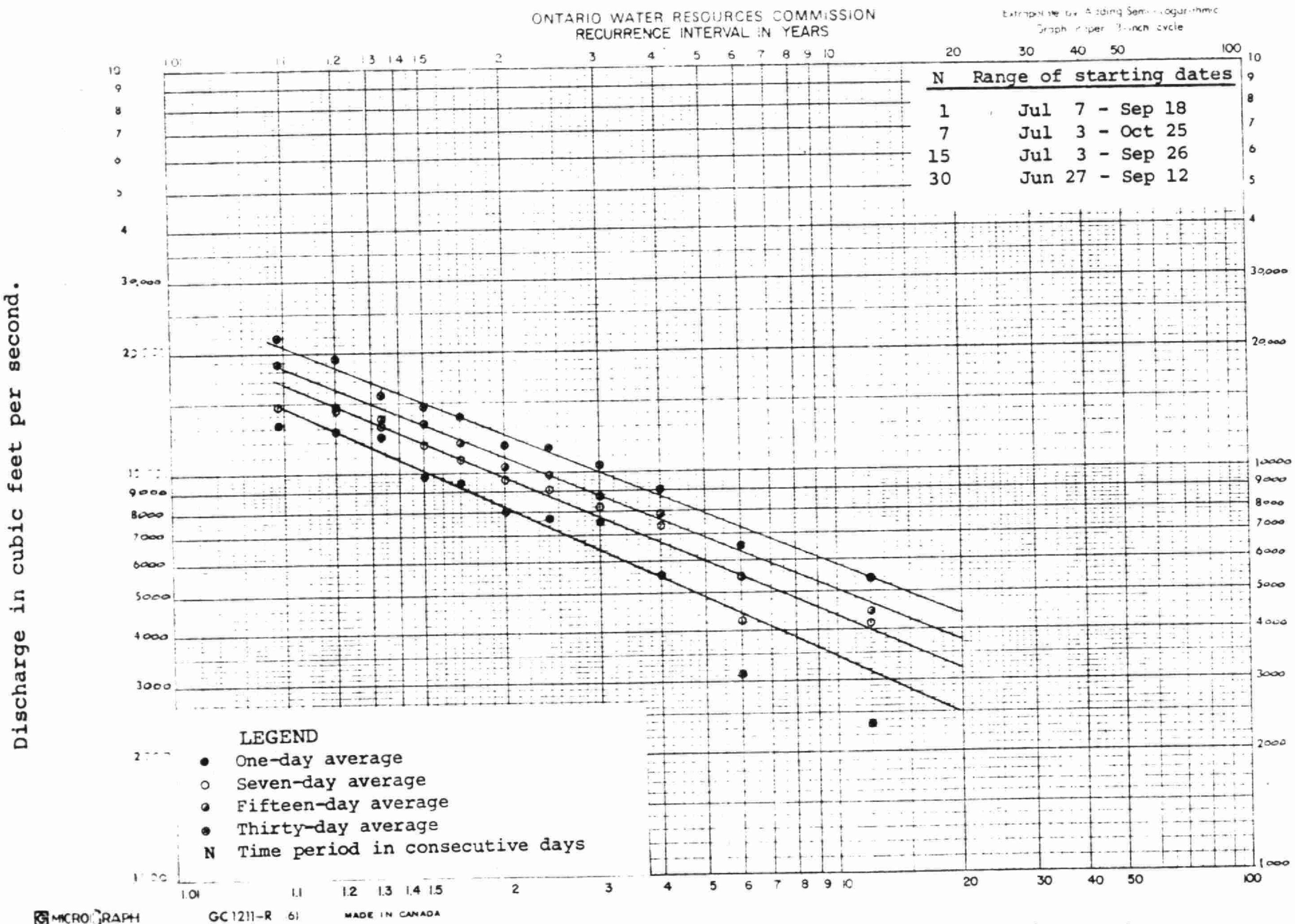

Figure 13. Frequency curves of low flows, Moose River at Moose River, at Station 04LG002, May-October, 1960-1970.

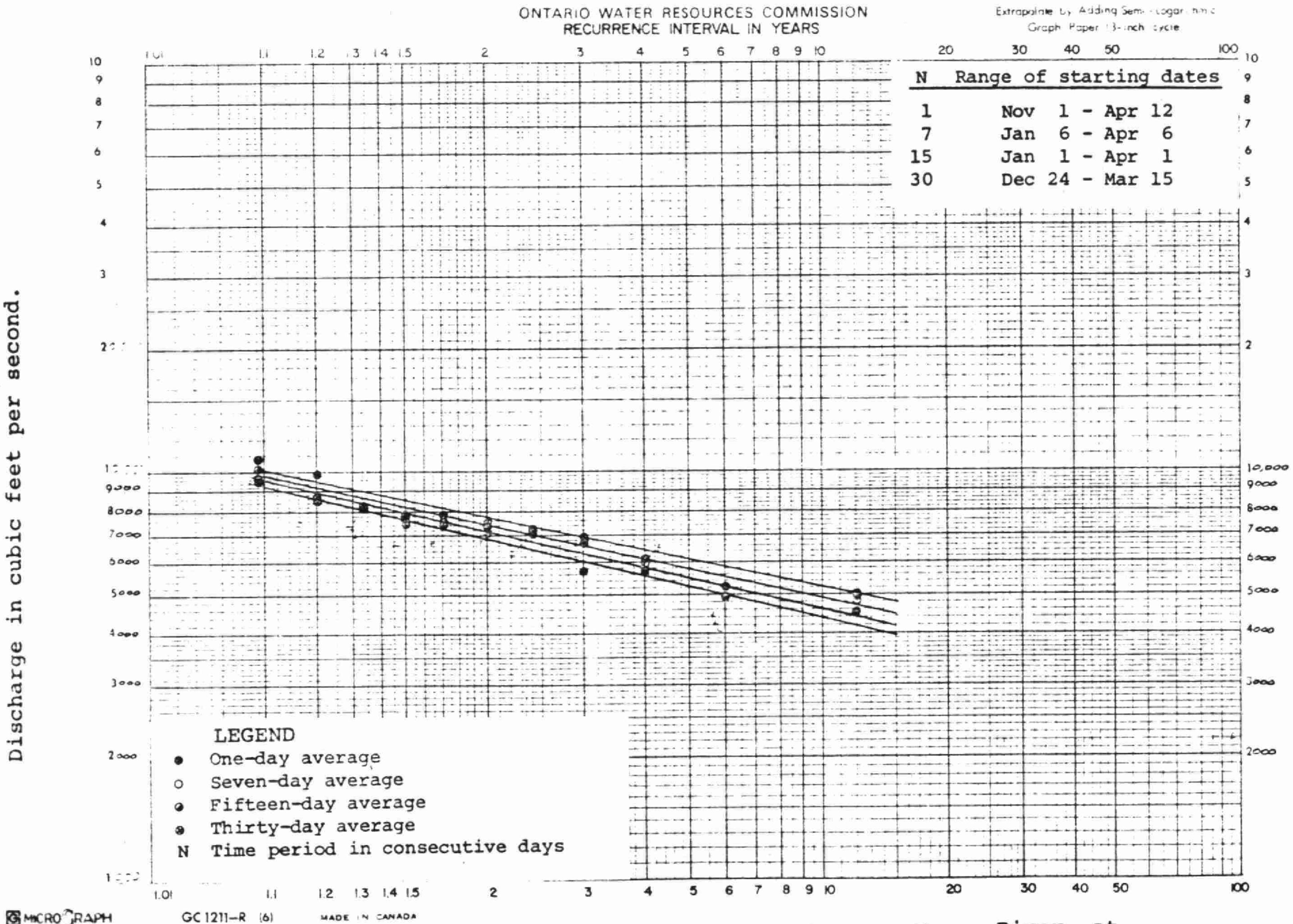

Figure 14. Frequency curves of low flows, Moose River at Moose River, at Station 04LG002, November-April, 1959-1970.

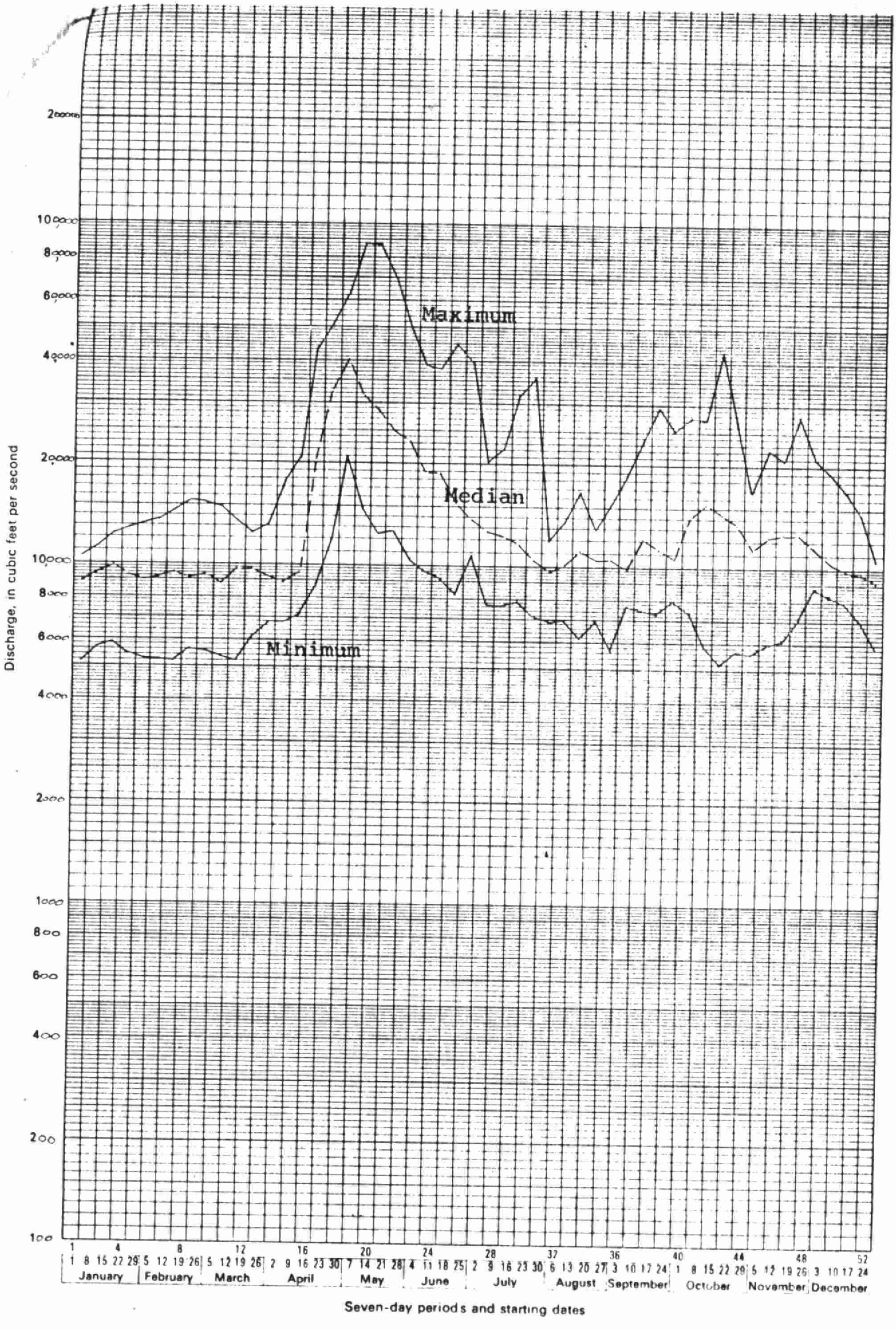

Figure 15. Traces of the maximum, median and minimum seven-day mean discharges, Abitibi River at Onakawana, at Station 04ME003, for the period 1960-1970. (drainage area: 10,600 square miles)

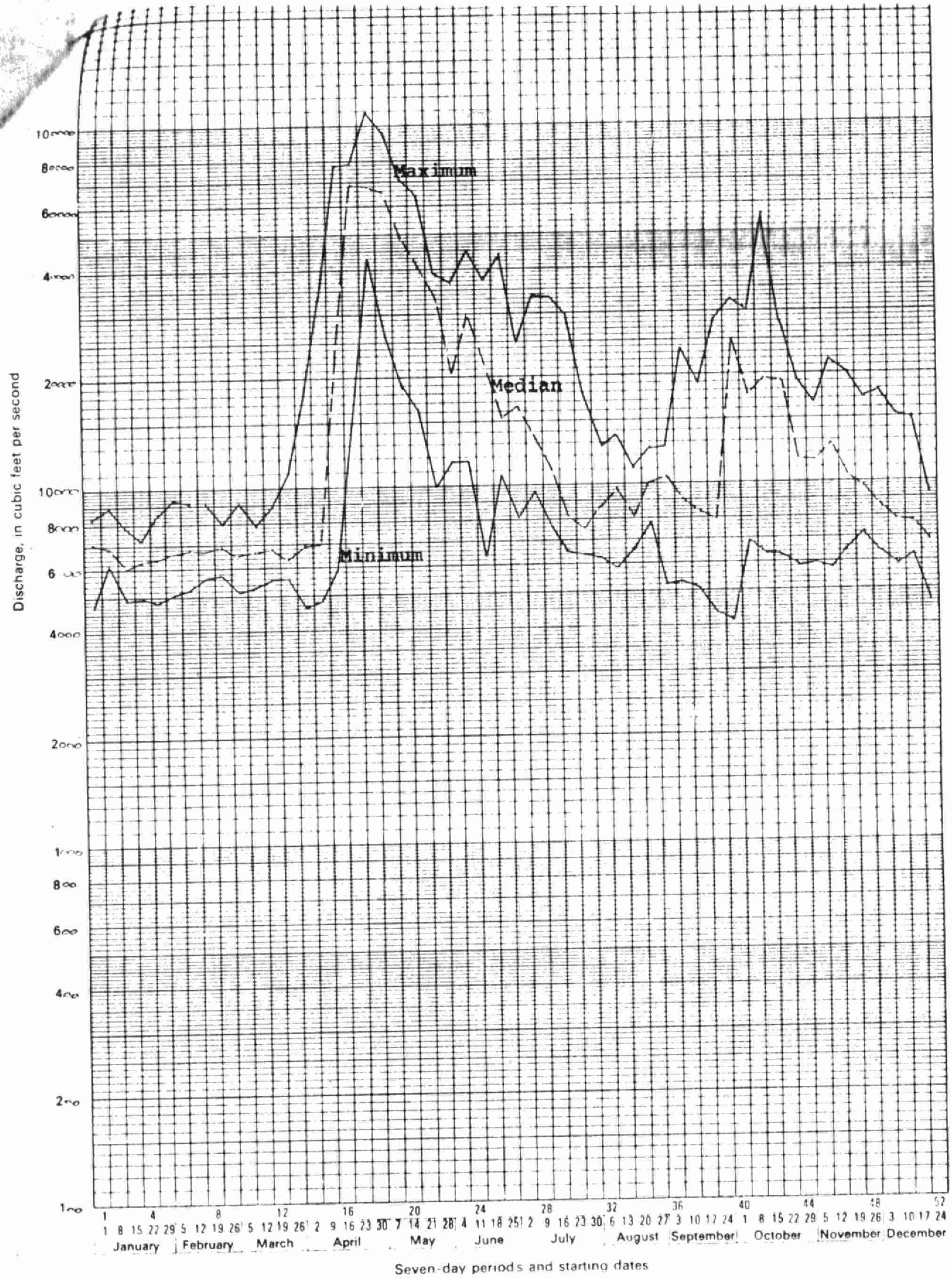

Figure 16. Traces of maximum, median and minimum seven-day mean discharges, Mattagami River at Little Long Rapids, at station 04LG003, for the period October 1963 - December 1970.

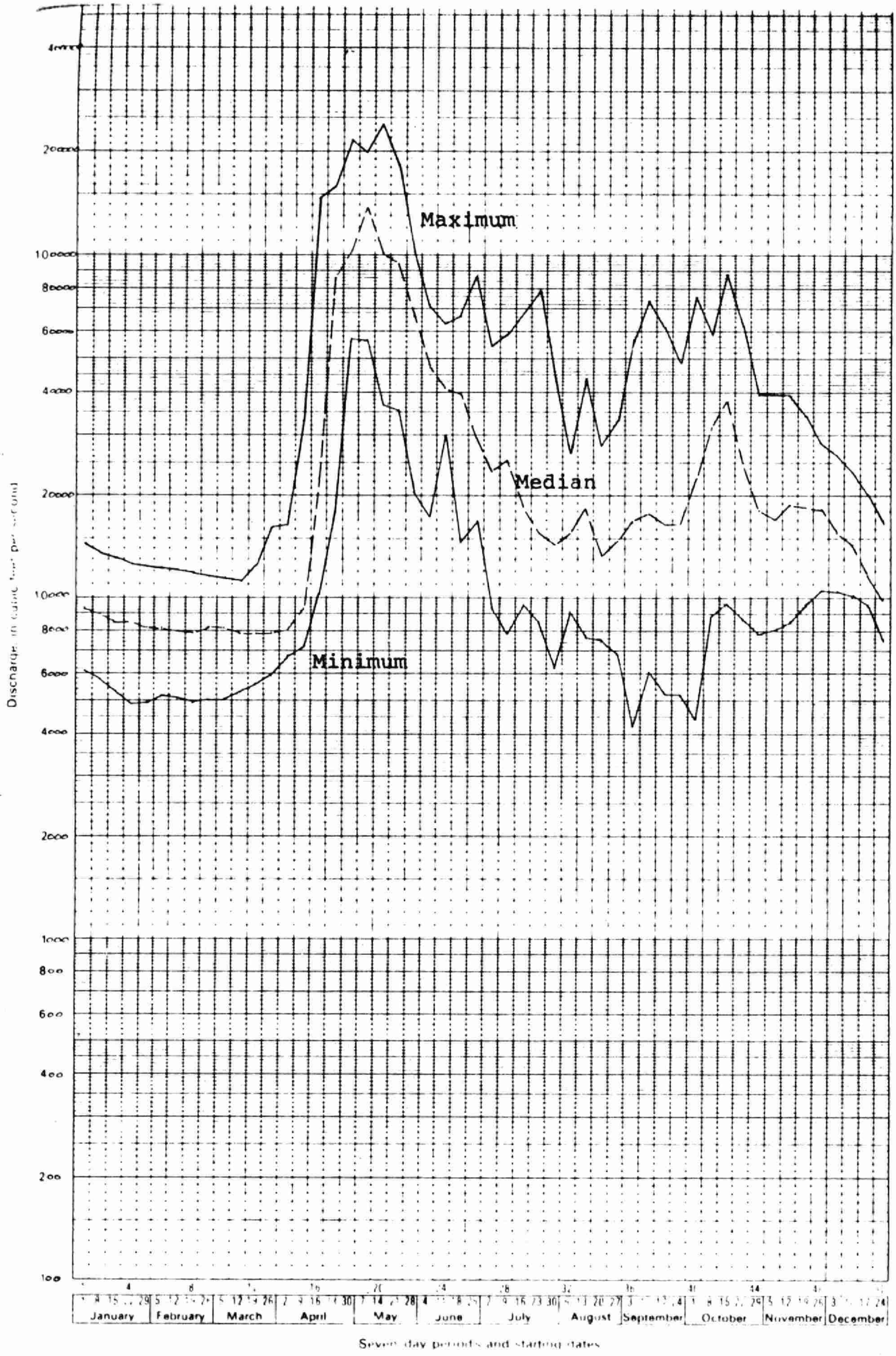

Figure 17. Traces of the maximum, median and minimum seven-day mean discharges, Moose River at Moose River, at station 04LG002, for the period 1960-1970. (drainage area: 23,600 square miles)

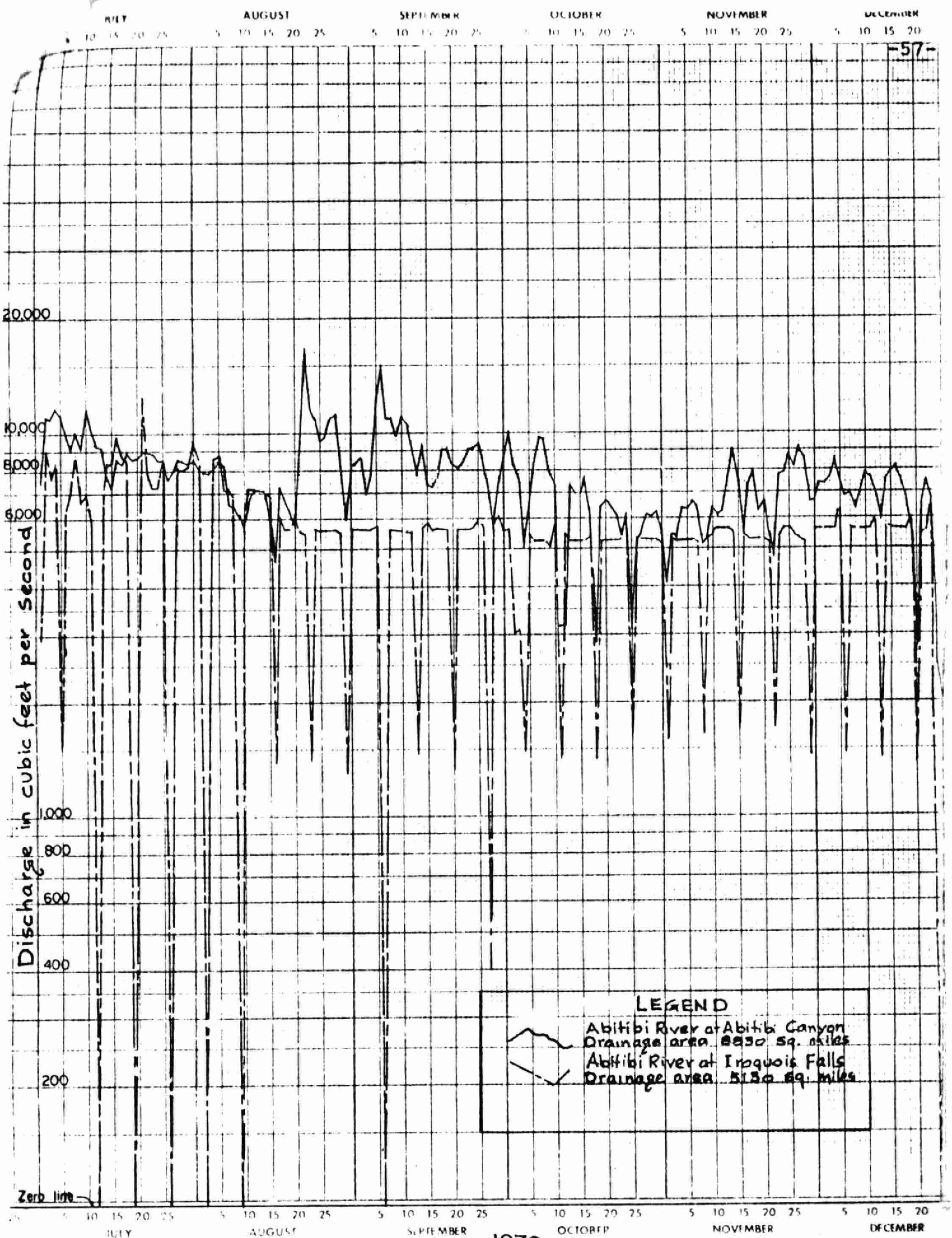

Figure 18. Streamflow hydrographs, Abitibi River at Abitibi Canyon, at Station 04ME002; and at Iroquois Falls, at Station 04MC001, for the period July-December, 1970.

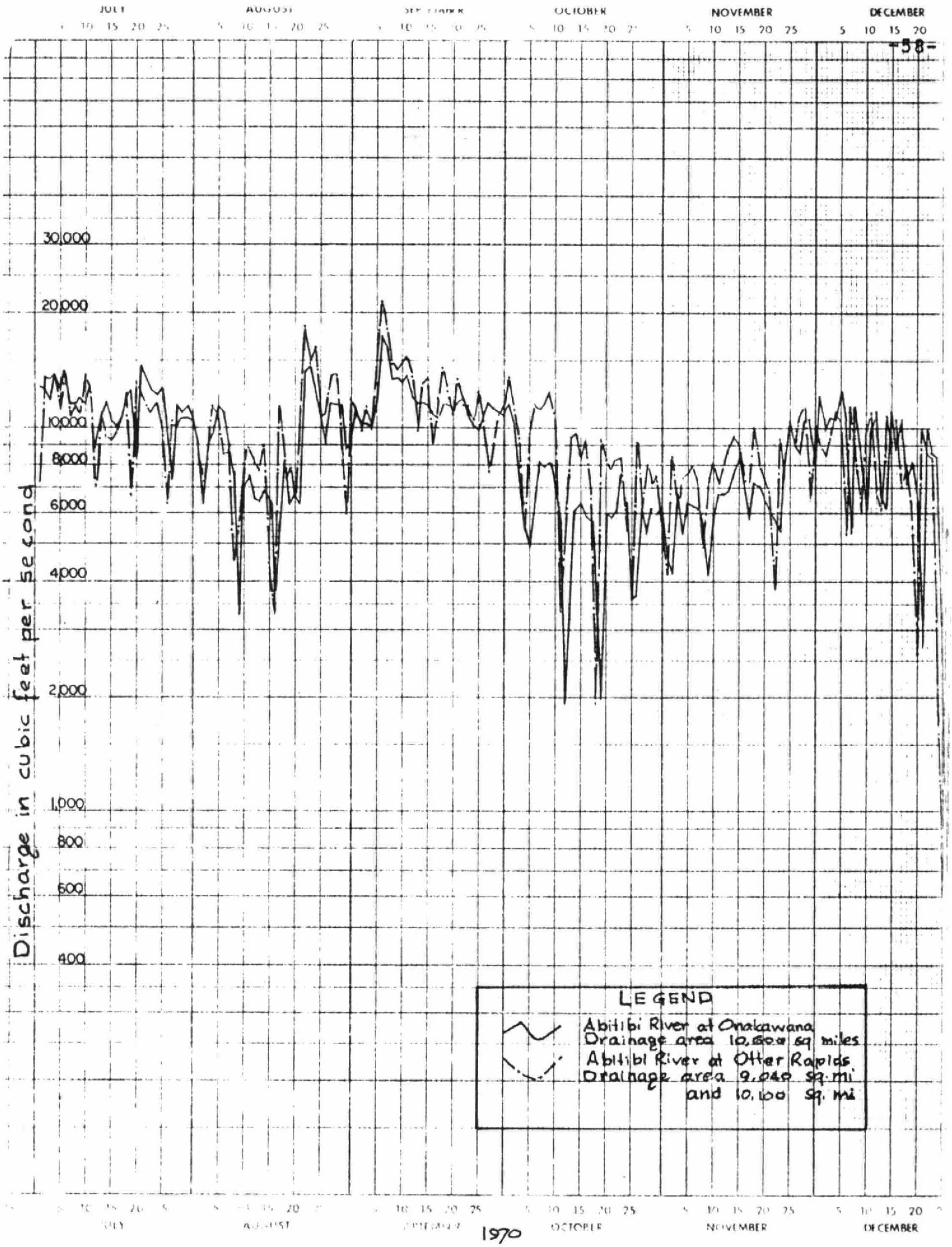

Figure 19. Streamflow hydrographs, Abitibi River at Otter Rapids, at Station 04ME004; and at Onakawana, at Station 04ME003, for the period July-December 1970.

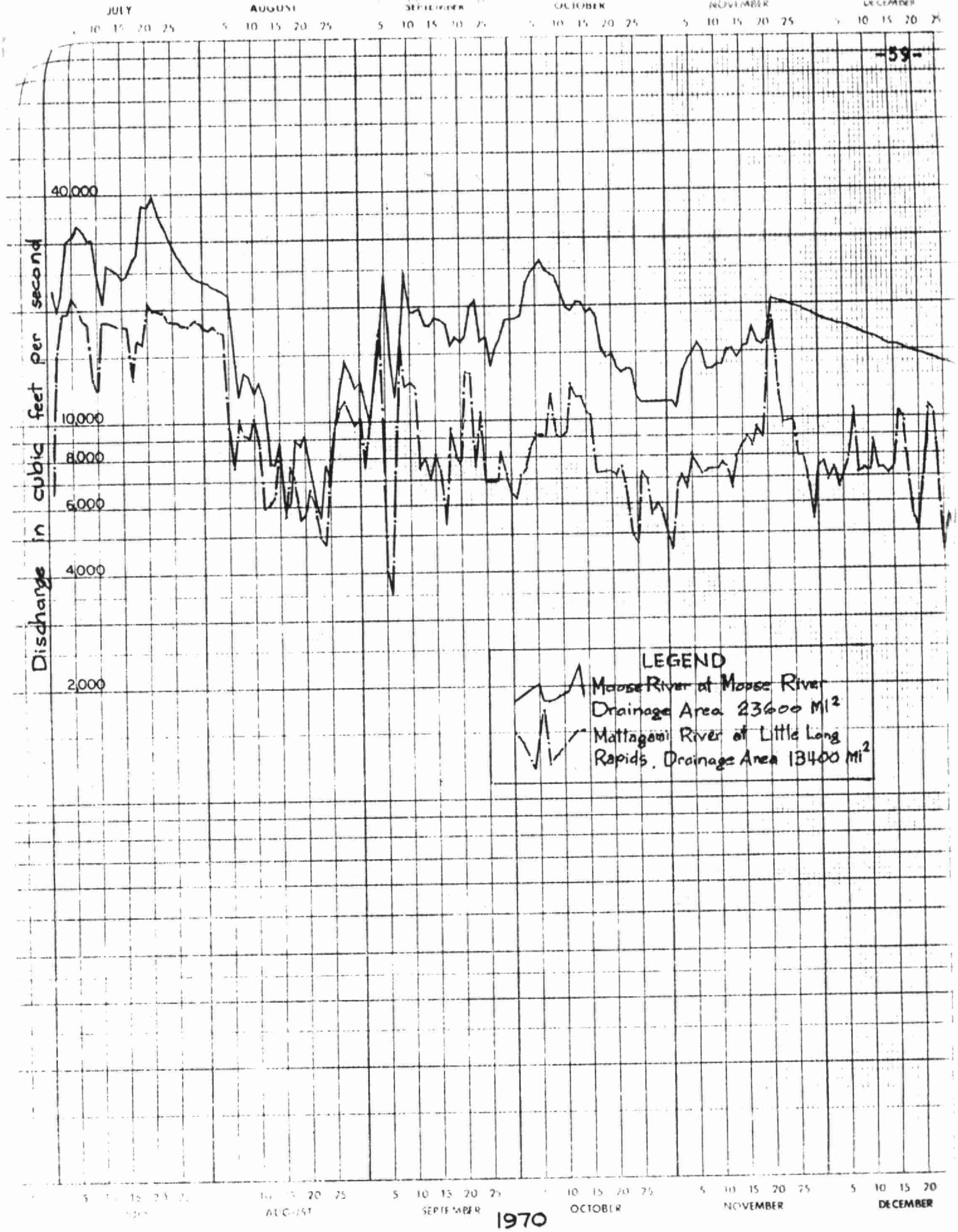

Figure 20. Streamflow hydrographs, Mattagami River at Little Long Rapids, at Station 04LG003; and at Moose River at Moose River, at Station 04LG002, for the period July-December, 1970.

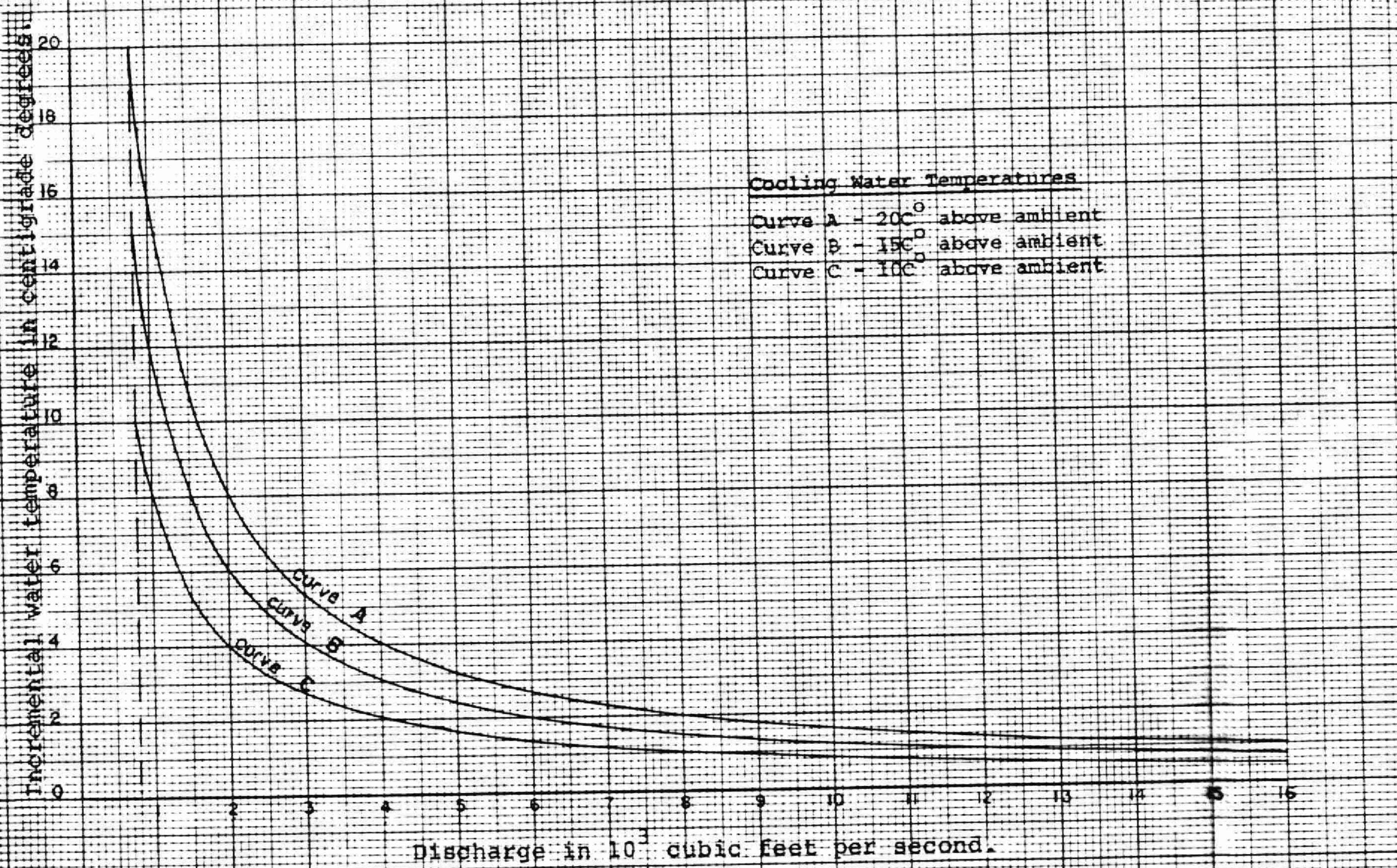

Figure 21. Relation between river discharge and incremental rise in water temperature above ambient resulting from the input of 800 cfs of cooling water at three selected temperatures above ambient.

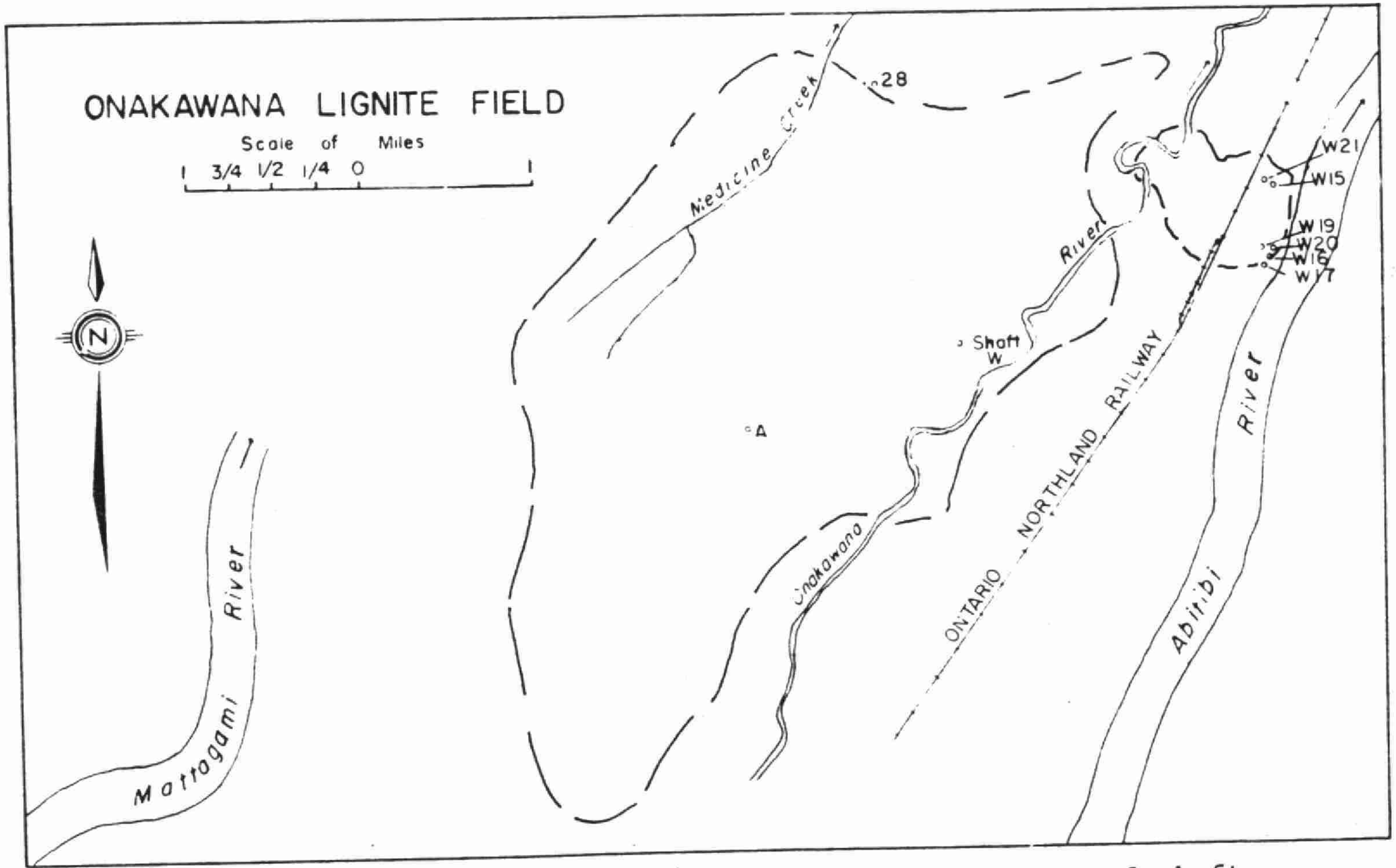

Figure 22. Onakawana lignite field, locations of test holes and shaft.

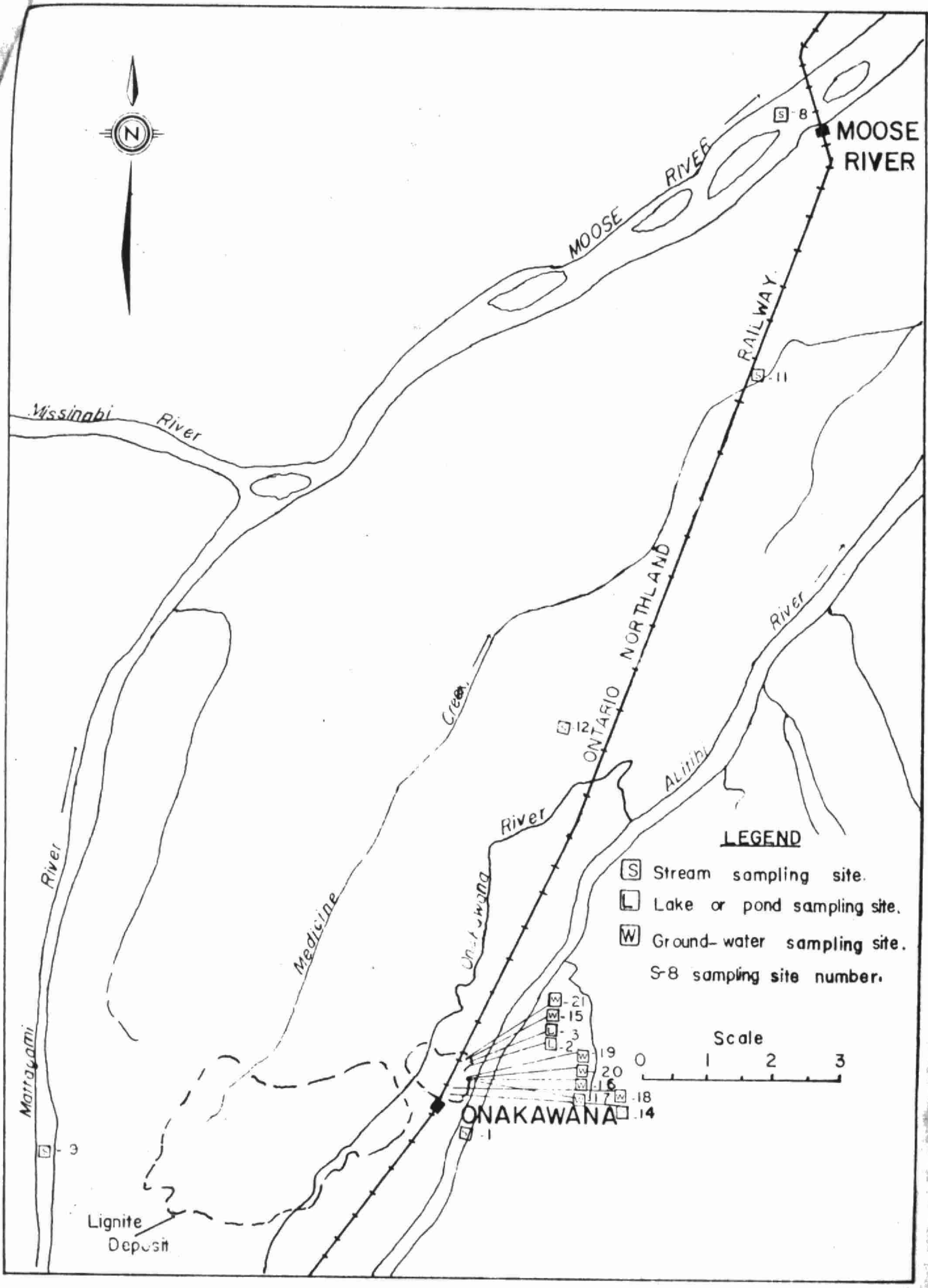

Figure 23. Onakawana lignite field and vicinity, water-quality sampling sites.

REFERENCES

Davis, S. N. and DeWiest, R. J.M., 1966, Hydrogeology, John Wiley & Sons Inc., New York.

Dyer, W.S., 1930, The Onakawana Lignite Deposit, Moosr River Basin; Thirty-Ninth Annual Report of Ontario Dept. of Mines.

Dyer, W.W. and Crozier, A.R., 1933, Lignite and Refractory Deposits of the Onakawana Lignite Field; 43rd Annual Report of Ontario Dept. of Mines.

Environment Canada, Inland Waters Branch, Water Resources Division, Water Survey of Canada, Magnetic Tapes on Historical Daily Discharge Data for Ontario Rivers.

Ferris, J.G., Knowles, D.B., Brown, R.H. and Stallman, R.W., 1962, Theory of Aquifer Test; U.S.G.S. W.S.P. 1536-E.

Hantush,M., 1964, Hydrualics of Wells, Advances in Hydroscience; Vol. 1, p. 281-432, Academic Press, New York.

Hvorslev, M.J., 1951, Time Lag and Soil Permeability in Ground Water Observations; Corps of Engineers, U.S. Army Waterway Experiment Station, Bulletin 36.

Muskat, Morris, 1932, Potential Distributions in Large Homogeneous Sand with Partially Penetrating Wells; Physics, Vol. 2, No. 5, p. 328-384.

Ontario Water Resources Commission, 1970, Guidelines and Criteria for Water Quality Management in Ontario.

Van Bavel, C.H.M. and Kirkham, D., 1948, Field Measurement of Soil Permeability using Auger Holes; Soil Sci.. Soc. Amer. Proc. Vol. 13, pp 90-96.

Date Due

AUG 25 1978			
SEP 15 1978			
NOV 3 1980			